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Instruments

THE MAGAZINE of MEASUREMENT and CONTROL

Vol. 22 JULY, 1949 No. 7

Including the *JOURNAL* of the Instrument Society of America

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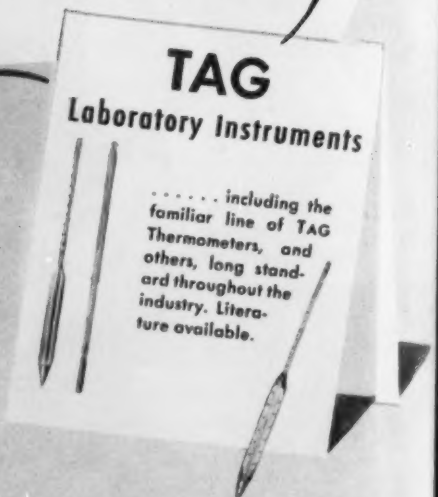
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J. F. BEHAR, Editor

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INSTRUMENT CONFERENCE & EXHIBIT
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1949

IT is not too early for readers in Portland, Maine, in Portland, Oregon, and points between, to make certain that they will attend the Fourth National Instrument Conference and Exhibit. Your editor knows full well that between eighty and ninety percent of *Instruments* readers are not members of the Instrument Society of America, but he doesn't have to prod ISA members: they've been receiving programs, hotel lists, airplane and bus charter terms, etc. It is rather to non-members that we aim to convey some of the enthusiasm which we've caught from several active ISA officials. This enthusiasm on the part of ISA officials is justified by: (1) the excellence of the programs by all participating societies; (2) the eagerness with which exhibitors are snapping up the booths; and (3) the large figures of promised attendance from nearly all sections.

(1) The programs by all participating societies are indeed excellent, in the sense that the major themes of sessions are of intense current interest and that most papers deal likewise with specific topics now on the minds of forward-looking Instrument Men.

The ISA's technical program is rich, diversified and chock-full of up-to-the-minute subjects. It begins on Tuesday morning with a session on "Maintenance and Operation of Instrument Mechanic Training Panel Discussion." The second session is likewise on Maintenance and Operation but the papers describe shop layouts, tools and equipment.

The ISA will hold three sessions on "Instrumentation for Testing" with a grand total of seventeen papers, most of them describing new developments.

Other ISA sessions are: "Production Processes" (three sessions, eight papers), "Inspection and Gaging" (two sessions, five papers), "Analysis Instrumentation" (one session) and "Transportation" (one session).

The American Society of Mechanical Engineers will hold three sessions with a total of nine papers by authors from industrial plants as well as from the National Bureau of Standards and other institutions.

The American Institute of Physics will hold sessions on Monday and Tuesday mornings. Seven papers will be presented, most of them reflecting current interest in nuclear phenomena, in cosmic rays and in the latest models of particle accelerators; but one paper will deal with training graduate students and one will describe a new timer for seismic research.

The American Institute of Electrical Engineers will hold two sessions (Thursday and Friday afternoons) with a total of nine papers. Five of these papers will be presented by instrument-company engineers and will describe new commercially-available developments; but there will also be papers by scientists with the National Bureau of Standards, a public utility, a university and a firm of consulting engineers.

The National Telemetering Forum (Monday and Tuesday mornings and afternoons) will attack some of the new problems, such as those posed by airborne equipment.

(2) The eagerness with which exhibitors are snapping up booths can only mean that they have many improved and refined products to show you. The proportion of "revolutionary new" devices will be smaller than it was before, when war-time inventions were translated into commercially-available instruments; few of the products to be exhibited this September will be experimental; even the many new models will be thoroughly service-tested.

(3) The "sure-to-come" totals from nearly all regions are large enough—even now, in late June—to fill with joy the ISA officials in St. Louis and the national committeemen elsewhere who have been working so hard these last few months. Rumor has it that a couple of jubilant St. Louis officials want to bet that their beloved city will draw a bigger attendance than did Pittsburgh in '46, Chicago in '47 and Philadelphia last year. It is not improbable that many *Instruments* readers from Portland, Oregon, Portland, Maine, and points between, will help break the attendance record: because the Conference and Exhibit are extremely good and because (as often declared on this page for many years) *Instruments* readers, having A KEEN SENSE OF VALUES, know a good thing when they learn of it.

This issue consists of two parts, bound separately. Part two is *The 1950 Instruments Index*, a buyer's guide issued every two years and sent free of charge to every subscriber. Your copy should reach you in the same envelope as Part One. Please advise the Circulation Department immediately if it has not reached you. Owing to the extra production problems (and to the fact that we have a new printer, outside of Pittsburgh) this two-part issue will probably come off the presses much later than usual.

LETTER

To the Editor of *Instruments:*

We are taking this opportunity to call your attention to an erroneous understanding of the Eclipse-Pioneer "Convectron" Tube which was discussed by Mr. C. C. Minter in the April 1949 issue of *Instruments*, page 322.

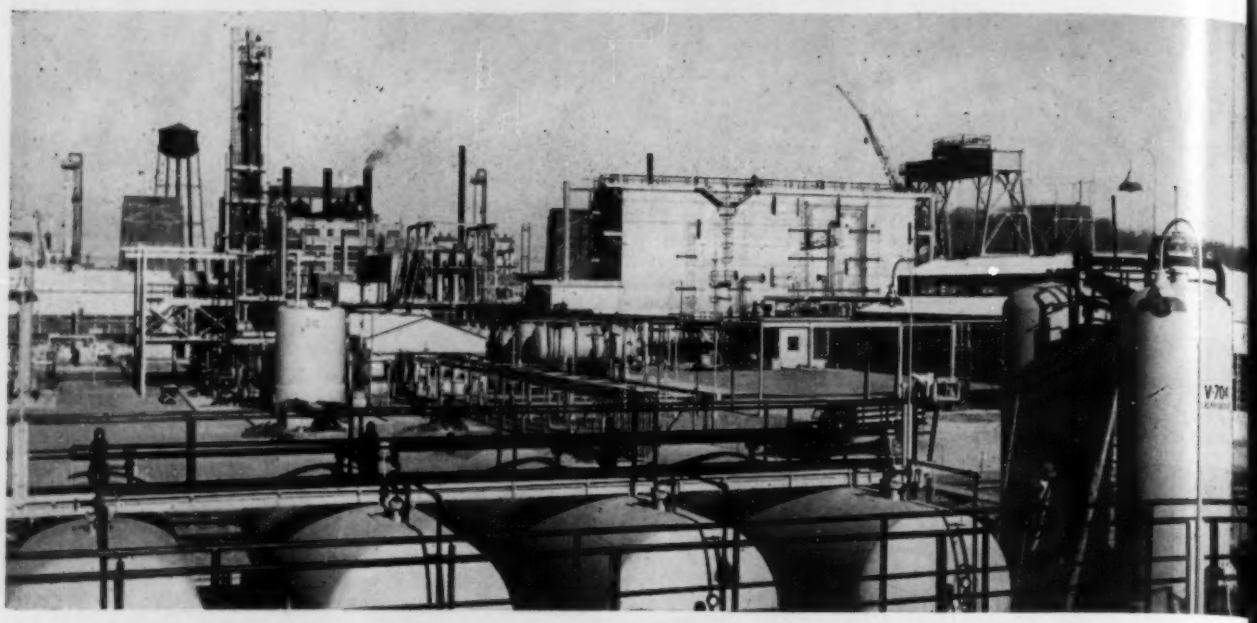
Mr. Minter describes the "Convectron" Tube in part as consisting of "a heater coil in the vertical portion of a Y-shaped tube filled with argon, [which] produces convection currents which flow up the two branches of the Y. At the tip of each branch of the Y is a temperature-sensitive resistor, connected with other resistors to form a Wheatstone bridge . . . Convection currents heat the two sensitive elements . . . giving a quantative indication of the angular displacement from the vertical."

Apparently Mr. Minter has mistaken a coil spring which serves to maintain the filament taut as a heater coil. In the Eclipse-Pioneer "Convectron" a 0.005-in. nickel wire filament is suspended in the center of each branch of the Y and extends over its entire length. This wire carries the bridge current and is heated therefrom. It is the effect of this heat on the surrounding gas which sets up the convection currents which in turn affect the temperature of the wire and thus its resistance, which change develops the bridge signal.

In Mr. Minter's discussion of an "Improved Modification of the Convectron," he states that "In the Electric Level, there is no external heater-coil for the production of convection currents but each sensitive temperature element acts as its own heater, [therefore] equilibrium is reached much more quickly . . ."

Duplication of our Tube thus becomes evident and Mr. Minter's comparison of this aspect of the two devices is meaningless.

ECLIPSE-PIONEER DIVISION
BENDIX AVIATION CORPORATION
June 15, 1949 CLARK SMITH, Advertising.



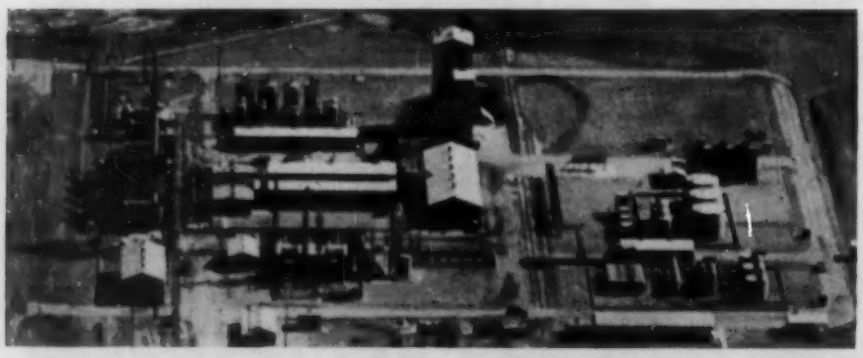
Hydrogenation Demonstration Plant. Product storage tanks in foreground; distillation facilities at left; converter stalls at right center. *(Bur. of Mines photo)*

Instrumentation Helps Cut Pattern *of* Know-How *for* New Fuels-*from*-Coal Industry. 1—HYDROGENATION

EDITOR'S FOREWORD — On May 8 the U. S. Bureau of Mines dedicated two synthetic fuel plants at Louisiana, Missouri. These plants will demonstrate the respective merits of two basic processes for converting American coals to oil: (1) direct hydrogenation and (2) Fischer-Tropsch synthesis. These processes are complementary rather than competitive; their products range from heavy fuel oil and waxes to jet fuels and aviation gasoline. Both plants bristle with engineering wonders, including advanced measurement, telemetering and automatic-control methods.

The coal-hydrogenation plant, now ready for production, was built at a cost of $10,000,000 under an engineering and construction contract awarded to Bechtel Corp. of California in May 1946. An article describing this new hydrogenation process appears herewith; it is followed by another article devoted entirely to the measurement and automatic-control devices — many of them of new designs which will help to create other new industries and to modernize existing industries.

At this writing (early June) the gas-synthesis demonstration plant is still under construction; it is scheduled for completion this year. A contract for its design and construction was awarded to Koppers Co., Inc., of Pittsburgh, Penna., in March 1948, at an estimated cost of $5,000,000. In a few months *Instruments* will print another pair of articles: one on this new synthesis process and one on its instrumentation.—MFB



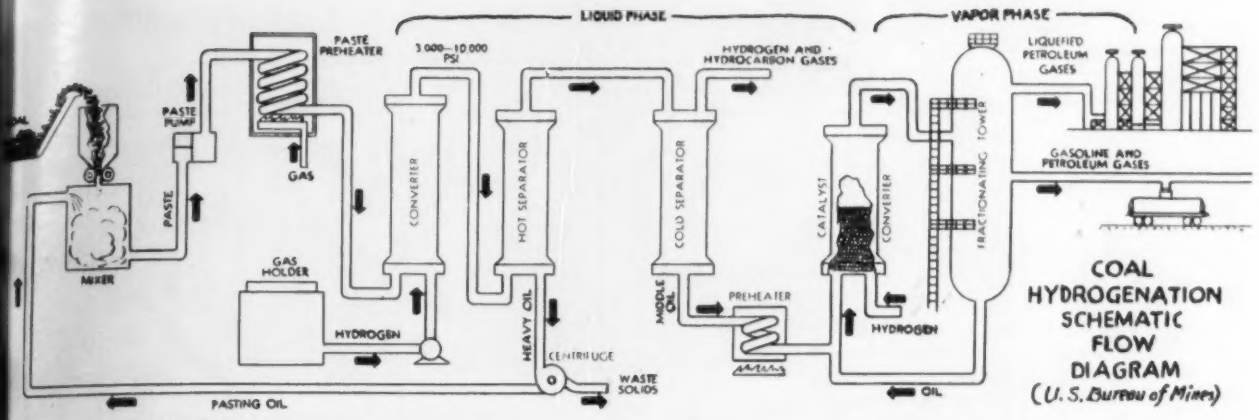
Air view of the hydrogenation plant. The concrete stalls are the dark structure seen edgewise at left. In upper center, coal and paste preparation buildings. In front of these is the compressor house; to its left the pump house. Control house is between pump house and stalls. In front of these houses is the distillation area; beyond them is the heavy-oil area. *(Bureau of Mines photo)*

CHEMICALLY, crude petroleum contains more than twice as much hydrogen as does coal. To convert coal to finished gasoline, hydrogen is added to the coal catalytically under high pressure and temperature. The plant was designed to operate at 10,000 psi. pressure in two major steps. Liquid-phase hydrogenation accomplishes liquefaction of coal, and vapor-phase hydrogenation converts the liquefied coal to gasoline and byproducts. The output of the plant will be 200 to 300 barrels of gasoline a day, depending upon the coal and catalyst used.

Dried, pulverized coal is mixed with a small amount of catalysts and with heavy oil previously obtained from the liquid-phase process into a viscous paste which, with a small volume of hydrogen, is injected into a steam-jacketed radiant-type paste preheater by steam-driven plunger pumps operating at 10,000 psi. After the paste is heated to about 570 F., additional hot hydrogen and recycle heavy oil are added to jump the temperature to 640 F., circumventing coal-swelling difficulties that would occur around 600 F. In the remainder of the preheater the mixture is heated to 815 F., after it passes to the converters. The reaction is highly exothermic and, to limit the reaction temperature to about 930 F., cooling hydrogen is added to the converters at different points in controlled volumes.

From the second converter, the reacted products enter the hot catchpot where hydrogen and light ends separate from the heavy-oil slurry. "Letting down" the heavy oil to near atmospheric pressure is an extremely difficult step because the hot liquid contains large quantities of absorbed gases and abrasive solids. The heavy oil is freed from unreacted solids by centrifuging or by flash distillation with superheated steam and returned to the process as pasting oil.

The gases and vapors leaving the



COAL HYDROGENATION SCHEMATIC FLOW DIAGRAM (*U. S. Bureau of Mines*)

op of the hot catchpot are cooled in heat-exchanger system, and the condensed liquid and vapor are separated in the cold catchpot. The gas from the cold catchpot, containing about 70 per-ent hydrogen, is washed with water and oil at full pressure and then recycled through the system with fresh make-up hydrogen. The liquid products from the cold catchpot and from the wash-oil scrubber go through let-down systems where the pressure is reduced to 7 atm. and then charged to the distillation unit for separation into pasting oil and feed stock for vapor-phase hydrogenation.

The vapor-phase injection pumps, working at 10,000 psi., feed the charge, to which hydrogen is added, through a feed-product exchanger and a radiant-type vapor-phase preheater. This stream, completely vaporized, enters the top of a single converter containing six fixed catalyst beds. In this reactor the equivalent of the three former German operations (saturation, splitting, and dehydrogenation) is accomplished in one step. The reaction being sensitive to temperature variations, recirculated cooling hydrogen is added at every tray to keep the temperature between 912 and 930 F.

The products then pass through the feed-product exchanger, a cooler and a cold catchpot, where the condensed oil and hydrogen are separated. The hydrogen is returned to the circulating compressor, and the liquid passes through a two-step let-down system to the vapor-phase distillation unit for separation into recycle stock and finished products. Hydrogen is added to both systems to maintain the working pressure, and the make-up to recirculation ratio is 1:5.

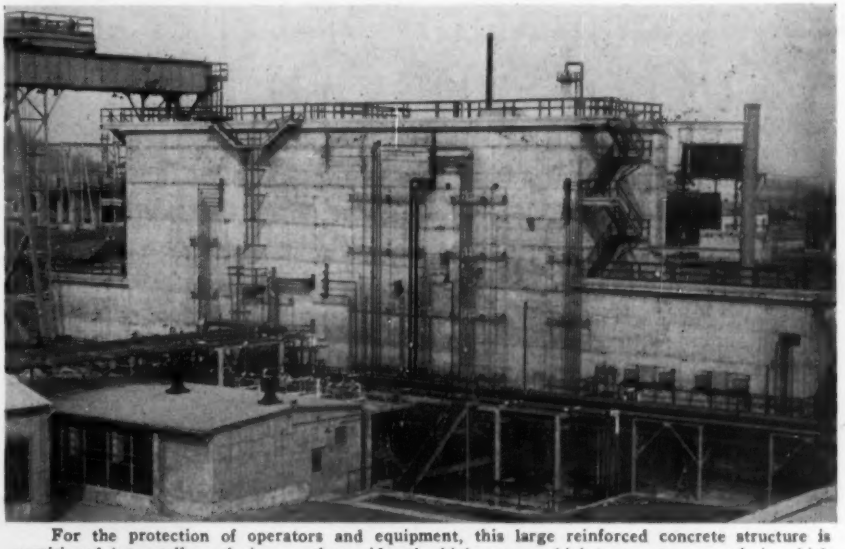
The 120,000- to 200,000-cfh. make-up hydrogen is made by reacting natural gas with steam at 1,700 F. in one of the former Missouri Ordnance Works' cracking furnaces over a nickel catalyst. The cracked gas passes through a shift converter at 800 F. and after cooling is stored in a 300,000-cfh. gas holder. Two 2500-hp seven-stage compressors compress the gas to 11,000 psi. Between the third and fourth stages, the CO_2 is scrubbed out with water and, after the seventh stage, the CO and half of the nitrogen are removed in a purification bomb.

Temperature measurement within the converters is taken through a centrally located pyrometer tube containing the thermocouple elements. The measurements at the various levels are transmitted from these elements to recording instruments in the control house.

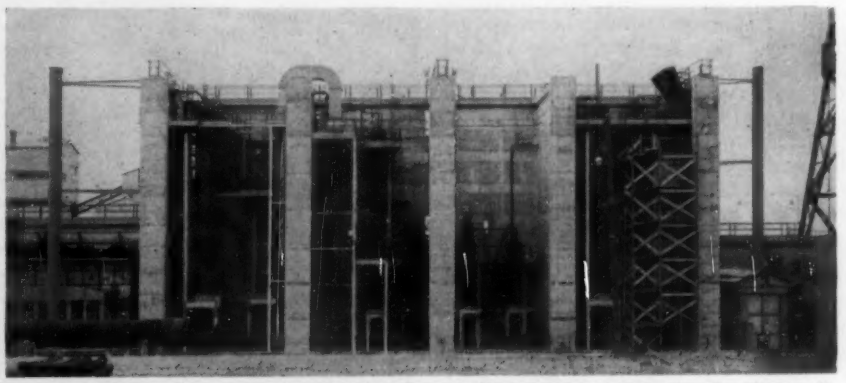
All high-pressure vessels are within a heavy-walled reinformed concrete structure, 193 feet long, 28 feet wide and 58 feet high, open on the top and rear. To minimize the danger from possible fires or explosions, the structure is divided into 6 stalls by 14-inch concrete walls. A 130-ton Gantry crane with a 70-foot lift straddles the structure and facilities handling the heavy equipment.

The extensive instrumentation used in the plant to facilitate the collection of data and to reduce the manpower required for operation through automatic control is, for the most part, an adaptation of existing American practices. Special designs were required, however, for measuring small differential pres-

(*Concluded on page 578*)



For the protection of operators and equipment, this large reinforced concrete structure is partitioned into stalls enclosing on three sides the high-pressure high-temperature vessels in which coal is converted to oil. The squat building nearest the stalls is the control house. The 130-ton traveling Gantry crane (left) straddles the stalls, can carry largest vessel. *(Bureau of Mines photo)*



Equipment in the three stalls at left liquefies coal. Vapor-phase equipment in other three stalls converts middle oil products to gasoline. All operations here are at 10,300 psi. and at temperatures up to 900 F. Hydrogen serves both in the reaction and to cool the giant converters which weigh nearly 100 tons each. *(Bureau of Mines photo)*

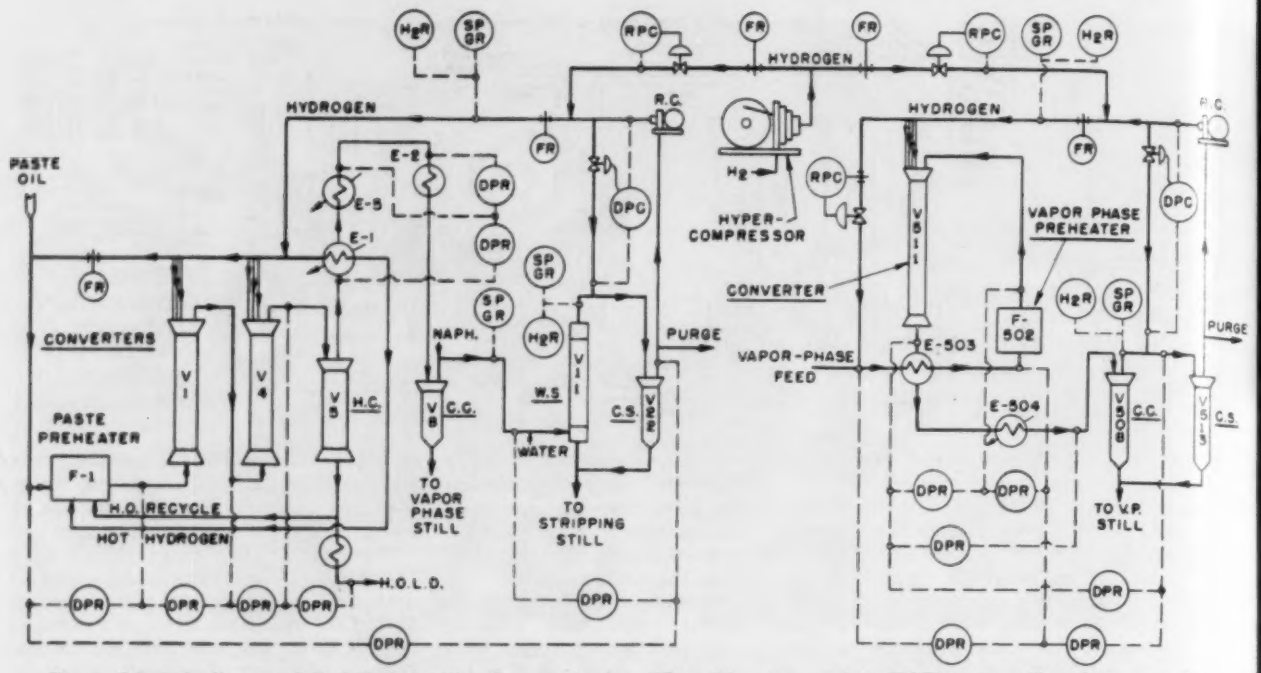


Fig. 1. Schematic diagram of Coal Hydrogenation Process, showing differential pressure points (DPR) and auxiliary instrumentation. DPR—differential pressure recorders; DPC—differential pressure controllers; FR—flow recorder; RFC—recording flow controller; RPC—recording pressure controller; SPGR—Specific gravity recorder; H_2R—hydrogen recorder; H.C.—hot catchpot; C.C.—cold catchpot; W.S.—wash oil scrubber; C. S.—compressor suction trap; R. C.—recycle compressor.

Instrumentation *of* Federal Bureau *of* Mines' COAL HYDROGENATION PROCESS *at* Louisiana (Missouri) Demonstration Plant

By S. D. ROSS and HANK CABOT, Brown Instruments Div. of Minneapolis-Honeywell Regulator Co.

EXTENSIVE use of industrial measuring and controlling instruments at the coal-to-oil demonstration plants at Louisiana, Mo., is apparent even to the uninitiated visitors. The large numbers of these automatic devices for checking, recording and controlling temperatures, pressures, flows, liquid levels and other variables makes this American plant obviously much more "instrumentized" than plants in Germany where the process originated.

The Bureau of Mines has taken full advantage of modern industrial instrumentation in operating the complex coal hydrogenation process. Many supplementary instruments have been installed for experimental purposes to gather valuable operating data and to accommodate changes in processing various types of coal. Estimates on commercial-scale plants, with all instruments necessary for operation, indicate that the over-all plant investment can be reduced by a fourth by the use of instruments and other process improvements.

In the subsequent sections of this article, certain "General Instrument Data," common to several portions of the process are first presented. Following this section, the process itself is considered, in the light of the instrumentation problems common to various phases of the process, under the following major headings:

B.—Low-pressure Auxiliary Operations
C.—Paste and Vapor Phase Preheaters
D.—Liquid and Vapor Phase Converters
E.—Hot Catchpot
F.—Cold Catchpots and Associated Equipment

Throughout this article it is assumed that the reader has become familiar in general with the process itself, as covered by the excellent descriptions available on the subject from the Bureau of Mines. (See foregoing article.)

A—GENERAL INSTRUMENT DATA

Measurement and control of all the major process variables in the coal hydrogenation process presented many new problems to the instrumentation engineers of Bechtel Corporation and the Bureau of Mines, as well as to the instrument suppliers. Certain of the unusual solutions were specific to one phase of the process and are discussed in later sections covering that phase. Others apply generally throughout the process and are described briefly below.

For reasons of safety and convenience in operation, all major process instru-

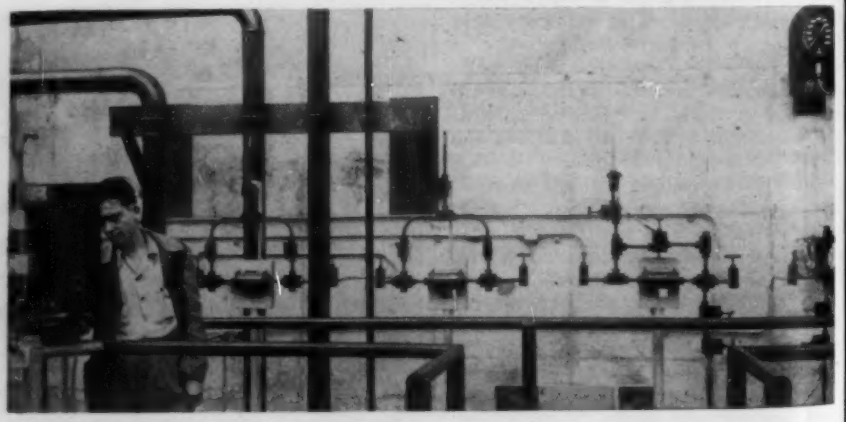


Fig. 2. View looking toward explosion stall, showing Statham differential-pressure transmitters.

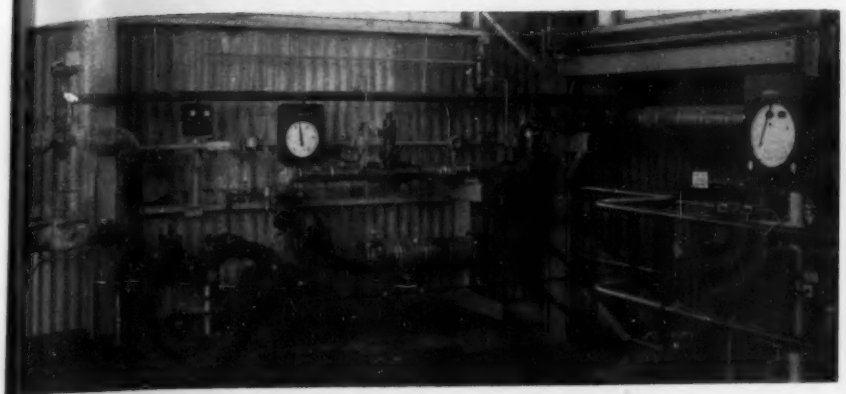


Fig. 3. Northwest corner of high-pressure pumphouse balcony. At extreme right a pneumatic pressure transmitter for coal-paste inlet. Circular-chart instrument in center is an indicating flow meter for viscous coal paste. Connected to it, at right, is a steam-jacketed area-type meter body which is connected to a recording flow meter located in the central control room. Valve at left is commanded by a pressure controller for regulating back pressure on recirculating coal paste.

ments in the high-pressure area are panel-mounted in a centralized control room (Figs. 6 and 7) protected from the high-pressure lines and vessels by a 12-inch reenforced concrete wall. Here, too, are located emergency handwheels for manually operating valves on all important high-pressure lines entirely independently of the automatic-control equipment.

In the low-pressure areas, separate smaller panels are located for the group of instruments employed in the coal and coal paste preparation processes.

Temperature

All temperatures in the high-pressure area are measured by means of thermocouples connected to panel-mounted "ElectroniK" potentiometers which are either indicators, recorders, or recorder-controllers. Most recorded temperature points are also wired to pushbutton switches by means of which the thermocouple can be checked from an indicator. The switches and indicators, used for many other temperature checkpoints, are also panel-mounted in the control room.

Thermocouples installed on high-pressure lines are of two types, namely: (1) those for clean liquids or vapors where the wires are protected by a special thermowell, and (2) those for liquids containing solids where a special "skin" thermocouple assembly is used to measure the external surface temperature of the pipe. The first type is similar in appearance to a standard thermowell but has several important design features. The thermocouple junction end is of a smaller diameter to increase heat transmission through the necessarily thicker walls of the well; and a lens ring is machined near the opposite end for high-pressure flange connection in a pipe tee.

The skin type thermocouple assembly is provided with a conventional protecting tube having a short section of high-pressure tubing on the end to be attached to the process line. The temperature-sensitive tip of the two thermocouple wires is formed in the shape of a button which is pressed tightly against the line when the thermocouple assembly is installed. The tube is welded to the pipe and the whole area around the assembly and pipe is covered with standard pipe insulation to prevent heat-loss errors.

For the control of temperatures, separate Brown "ElectroniK" circular-chart potentiometers equipped with "Air-O-Line" pneumatic control are used. This type of control provides a throttling action of the controlled valves, such that the temperature is maintained close to the desired value in spite of varying requirements for heat in the process. Each of these instruments is equipped with a "thermocouple burnout" feature which causes the controller pen to run upscale and open or close the control valve as the process safety may require, in the event of any open circuit in the thermocouple or its connecting extension wire. Auxiliary mercury switches are also incorporated in these instruments to energize signal lights and sound alarms in the control house should the temperature exceed the preset high limit.

Pressure

All pressure recorders, controllers, and recorder-controllers in the high-pressure area utilize the well-known Bourdon-tube primary element for measurements. The Fisher non-indicating pressure controllers used are locally mounted on the process equipment, but the Brown recorders and recorder-controllers are located in the control house and connected to locally-mounted indicating pneumatic transmitters containing the Bourdon-tube elements. These latter instruments obviate the danger and expense of piping high-pressure connections to the control room by converting the high pressures to corresponding air pressures in the range of 2 to 15 psi. near the point of measurement. Connected by one low-pressure tube to the recorder, these air pressures are accurately translated again in terms of the measured high pressure.

Flow-rate

The large majority of gas, liquid, and vapor flows in the hydrogenation process are measured on the differential pressure principle whereby an orifice placed in the flow line creates a pressure drop which is measure of the rate of fluid flow. Special vane type flow meters for small hydrogen flows and an area

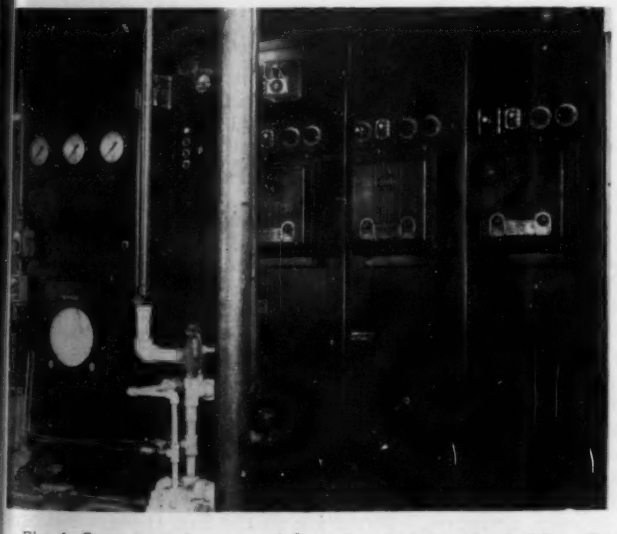


Fig. 4. Control panel on ground floor of paste-preparation building. Top left, three liquid level indicators and paste-feed and other storage tanks. Lower left, paste-oil flow controller. Upper right, three control units for automatic weighers.

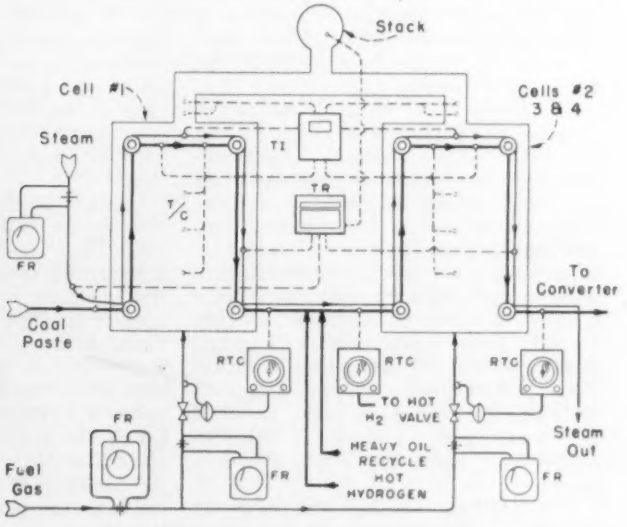


Fig. 5. Simplified Instrumentation of Paste Preheaters. TI—electronic temperature indicator; TR—multi-point electronic temperature recorder; RTC—recording electronic temperature pneumatic controller; FR—recording mechanical flow meters.

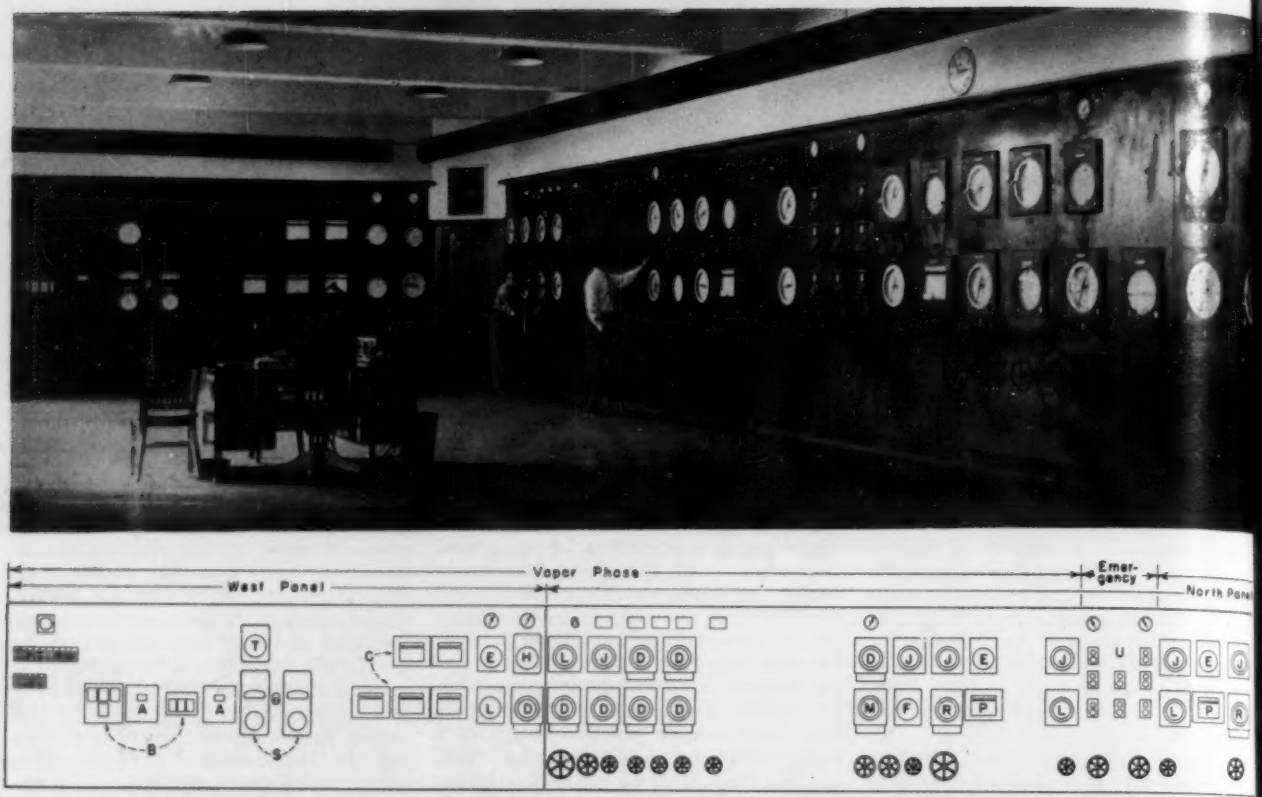


Fig. 6. West panel, and slightly more than half of north panel, of the huge control room.
The handwheels installed below the instruments are for manual emergency shut offs, a "must" protection on the project where explosion and fire hazards are present.

Panel Letter	Diagram Symbol	Type of Instrument	Quantity on Panel	Mfr.
A	TI	Indicating electronic potentiometer	3	Brown
B	..	Thermocouple switch cabinet	4	Brown
C	TR	Multi-point electronic recorder	10	Brown
D	RTC	Recording electronic temperature controller	20	Brown
E	PR	Recording pressure receiver for Bourdon tube pneumatic transmitter	6	Brown
F	RPC	Recording pressure controller with Bourdon tube pneumatic transmitter	2	Brown
G	FI	Flow indicator for Statham vane transmitter	12	Weston
H	FR	Recording low-pressure mechanical flow meter	4	Am. Meter
J	FR	Electronic recorder for Statham differential pressure transmitter	13	Brown
K	FR	Recording flow receiver for area meter transmitter	1	Brown

type flow meter for coal paste flow are described in subsequent sections dealing with the process instrumentation.

The orifice plate design for the high-pressure lines incorporates a lens ring construction on its circumference to provide the same pressure-tight flange connection used on all high-pressure pipe connections. Low-pressure fuel gas and steam lines permit the use of conventional orifice plates for the flow meters. In the latter case, standard "Metric" meters with the mercury manometer mounted directly on the back of the instrument case are employed. Most of these are locally installed near the point of measurement, while a few transmit the flow readings to panel-mounted recorders in the control room.

For the measurement of high-pressure flows two distinctly different types of non-indicating differential pressure transmitters are utilized, namely: (1) Statham elements for flows to be recorded only, and (2) special Brown electric meter bodies of the mercury manometer type for flows to be recorded and controlled. Both types employ separate panel-mounted "ElectroniK" circular-chart instrument for recording or control, being installed near the point of flow measurement and electrically connected by a single cable to the instruments.

The Statham element (see Fig. 2) operates on the principle that stretching or compressing wire causes changes in electrical resistance and that such a change can be a measure of the force acting on the wire. For flow measurement the differential pressure across the orifice plate is connected to the element in such a way that a force in one direction is created on four wires in the element. The wires are arranged so that two tend to be stretched by the force while the other two are compressed. Thus an appreciable resistance change, measured by the self-balancing instrument, is created as an indication of the flow.

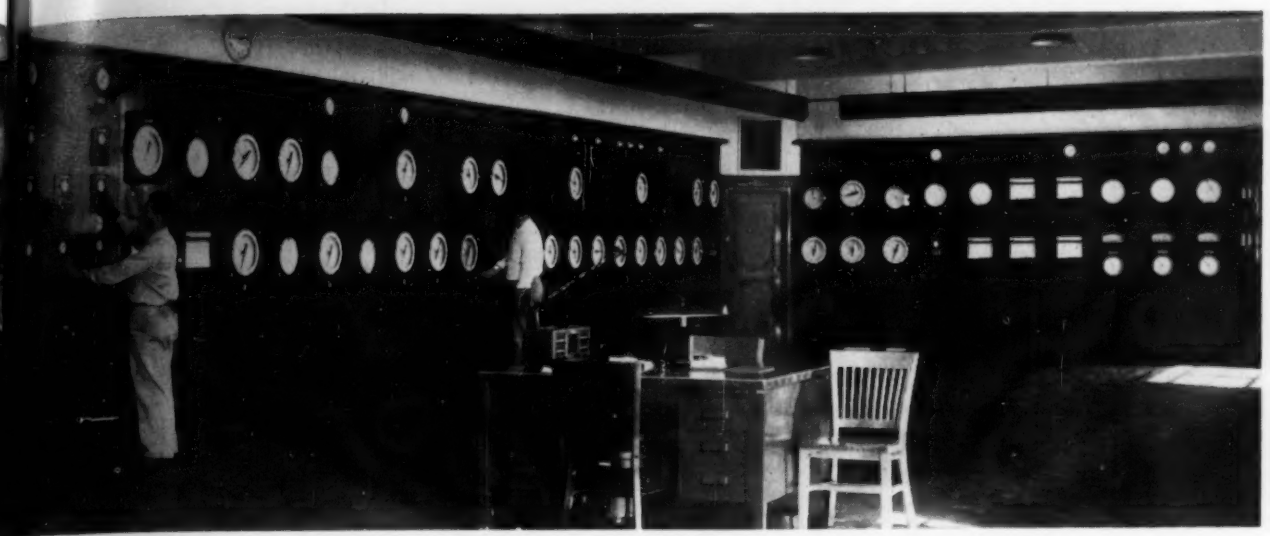
Use of the Statham element in this manner is still in the experimental stage, but shows promise of offering a relatively inexpensive means of flow transmission with high accuracy and sensitivity. For vital control applications, however, an adaptation of the Brown electric meter body was selected because of its proved principle. It comprises a mercury U-tube manometer to which the differential pressure across the orifice plate is connected. A float on the mercury is attached by a vertical rod to an armature in an inductance coil. Vertical movement of the armature, caused by changes in flow, alters a bridge circuit in the "ElectroniK" self-balancing instrument, which accordingly repositions the recording pen and actuates the pneumatic control mechanism.

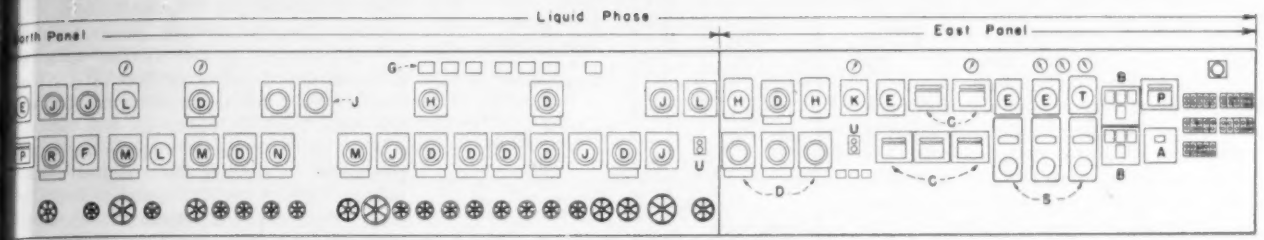
In combination with the self-balancing instrument these electric transmitters provide a reliable and sensitive means of flow measurement to be used as the basis for control. As in the case of the thermocouple pyrometers, the flow control instruments on the panel are equipped with manual control stations so that in emergencies the control valves can be pneumatically positioned by an operator in the control house.

For measuring the flows of heavy fluids and those containing a small amount of solids in the low-pressure area, displacement type flow meters are used. These are of either the Buffalo Meter or Automatic Liquid Meter design and operate on a principle similar to that of the well-known domestic water meter.

Differential Pressure Measurement

Because of the experimental nature of the process and the lack of full information on the fluid characteristics at high pressures and temperatures, it was desired to measure pressure drops along lengths of piping and across the various





Panel Letter	Diagram Symbol	Type of Instrument	Quantity on Panel	Mfr.
L	RFC	Recording electronic flow controller with high-pressure electric transmitter	7	Brown
M	RLC	Recording electronic level controller with high-pressure electric transmitter	4	Brown
N	RLC	Recording electronic level controller with "Gage-tron" element	1	Brown
P	DPR	Multi-point electronic differential pressure recorder for Statham transmitters	3	Brown
R	DPC	Recording electronic differential pressure controller with Statham transmitter	2	Brown
S	SPGR	"Ranarex" specific gravity indicator-recorder	5	Permutit
T	H_2R	Two-point hydrogen gas analyzer and recorder	2	Bailey
U	RMC	Remote manual valve control station	10	Fisher

Fig. 7. Slightly more than half of north panel, and east panel, of the huge control room.

Instrumentation for vapor phase occupies all of west panel and left half of north panel; that for liquid phase is on the right; and emergency controls are centralized.

eat exchangers and vessels. Such meas-rements also supply valuable informa-ion about the operation of the units, uch as coking in tubes or clogging of ines which cause a marked increase of he pressure drop.

Some fourteen pressure-difference oints were selected, with the expected rop varying in the range of 100 to 1000 si. These large differentials are far eyond the range of conventional man-meter type flow meters which are often sed for such measurements in commer-ial plants. The same design of Statham lement used for flow measurement, owever, is ideally suited for differen-ial pressure measurement without the ange limitation. These elements are stalled in the process area and con-ected to multiple record strip chart le tronic recorders in the control house (s e DPR's on Fig. 1).

Two additional Statham elements are us d to measure the differential pres-ur es between the outlets of the recycle ompressors and the inlets to the com-pressor suction traps in the liquid and vapor phases. These are each connected to a circular-chart electronic controller (labeled DPC on Fig. 1) which operates diaphragm-motor valves in the by-pass lines between these two points. Operating at 700-psi, differential pressure, these controllers perform the important function of controlling the by-pass flows at the proper values.

Liquid Level

In the low-pressure vessels several designs of non-indicating level controls or alarms, as well as level indicators are employed. These may be listed as follows: (1) Fisher displacement type with pneumatic control, (2) Varec float type remote indicator, (3) "Bin-Dicator" diaphragm type electric alarm, (4) Taylor diaphragm type with pneumatic transmission of level readings.

For the vessels under 10,300 psi., the same design of a special high-pressure electric meter body previously described is used for level measurement. Its method of application is described later under the description of unit process instrumentation, as are several other special level measuring devices.

Miscellaneous Variables

As a check on the composition of the gas streams in both the liquid and vapor phases, several Bailey hydrogen analyzers and recorders, together with "Ranarex" specific gravity recorders are used (labeled H_2R and SPGR, respectively, in Fig. 1). The gas samples are let down from 700 atmospheres to 10 inches of water through capillary tubing, which also tends to reduce the time lag of measurement. The hydrogen analyzer operates on the thermal conductivity principle, measuring the hydrogen content of the sample by its cooling effect on an electrically-heated wire as compared to that of a standard. Wires for the sample and standard are arranged in an electric circuit of the instrument.

The specific gravity recorder operates on the principle that the turning force imparted by the gas sample on an impeller-type fan wheel is directly related to the specific gravity of the gas. The turning force of air on a similar fan wheel is opposed to the sample wheel as a basis for comparison, and the difference in the two forces is mechanically connected to the instrument indicating pointer and to the recording pen.

To insure safe combustion of the fuel gas in the paste and vapor phase preheaters and in several other portions of the process, "Protectoglo" combustion safeguard controls are installed on the burners. These units detect the presence or absence of a flame by electrodes inserted at the burners. In the event of flame failure, they function to shut off the fuel supply as well as to energize alarm signal lights and horns in the control room.

Control Valves

For automatic control throughout the hydrogenation process, pneumatic-operated Climax diaphragm-motor valves are used almost exclusively. Receiving air pressure from the control instrument in the range of 2 to 15 psi., these valves are installed in the process pipe lines and function to position a throttling plug in an orifice within the valve body to vary the rate of flow.

In certain high-pressure let-down services, special control valves are used, having an angle-type body construction with a special Venturi-shaped outlet discharging through a single opening into a hardened surface (Stellite-faced) target tube. This design is found to greatly decrease wear on the valve body as caused by the high velocity effect of the throttled flow, in many cases combined with the abrasive effect of entrained solids.

The pneumatic motors for operating these valves are extra-large and are all equipped with valve positioners to increase the positioning ability of the valve. To further increase the power of the operator, the valves are equipped with a special travel-reducing linkage.

Normal pressure drops across the valves varies between 100 psi. in certain cases to 700 psi. in others. Several of the let-down valves, however, have drops as high as 675 ATMOSPHERES in one stage. Particularly in H.O.L.D., operating conditions for the valves are most severe, so that parallel valve arrangements are installed with provision to switch control from one to the other. These valves are a vast improvement over the German hand valves, which are said to have often worn out after several days' operation and to have had a maximum life of 30 days.

B—LOW-PRESSURE AUXILIARY OPERATIONS

The major phase of the coal hydrogenation process from instrument viewpoint, as well as the equipment standpoint, is the high-pressure area. Auxiliary operations conducted at conventional pressure and temperature ranges offer few unusual instrumentation problems and are covered only briefly in the subsequent paragraphs, with emphasis on the unusual control applications. These operations are the coal and paste preparation. Other auxiliary operations —such as heavy oil centrifuging or flash distillation, product recovery by conventional distillation, and power generation —involve standard instrument practice and are therefore not considered in this article.

Coal Preparation

Industrial instruments used for automatic control in this operation are panel-mounted on the ground floor of the coal preparation building and include (1) a Foxboro temperature controller on the furnace which supplies hot gases used to dry the pulverized coal in the ball mill; (2) a Wheelco combustion safeguard system on the fuel supply of the gas furnace, and (3) a Bailey oxygen analyzer and recorder for the gases out of the furnace.

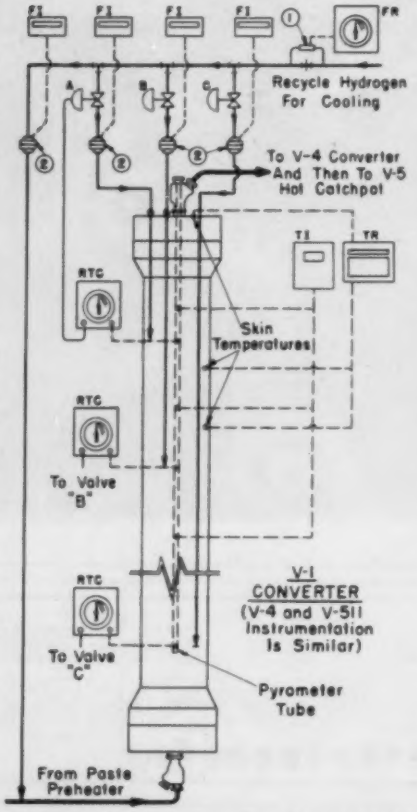


Fig. 8. Simplified Instrumentation of Liquid Phase Converters.
FI—electric flow indicator; FR—electronic flow recorder; TI—electronic temperature indicator; TR—multi-point electronic temperature recorder; RTC—recording temperature controller; 1—Statham differential pressure element; 2—Statham vane-type element.

Of particular interest is the special Kennedy Van Saun device for controlling the level of pulverized coal in the ball mill by operation of a Bailey disk feeder on the crushed coal inlet line. The controller comprises a panel-mounted unit which contains a small glass U-tube, one side of which is connected to a vertical tube installed in the ball mill to the level control point. This tube is normally subjected to the draft pressure in the mill when the level is below its bottom end and results in a certain level of liquid in the U-tube. When the level reaches the bottom of this tube, the change in pressure causes the U-tube liquid level to change and intercept a photoelectric cell, the amplified output of which commands the coal feeder.

Paste Preparation

Primary instruments used in this operation are panel-mounted on the ground floor of the paste preparation building (Fig. 4) and include: (1) three Taylor indicating level gages connected to diaphragm type transmitters installed on the bottom of the paste feed and other storage tanks, (2) three Jeffrey "Waytrol" control units for the automatic weighing scales which proportion the amounts of pulverized coal and dry catalysts to the paste mixer, and (3) a Brown recording paste oil flow controller which regulates the amount of oil to solids in the paste mixer.

In this stage of the process a number of auxiliary control devices are used for high-limit and supplementary control functions. For example, high- and low-level "Bin-Dicator" alarms are installed on the pulverized coal storage bin. Also, Taylor self-operating temperature controllers are used on such service as regulating low-pressure steam to the jacket of the coal paste mixer and to the paste feed storage tank, as a means of temperature control. Fisher displacement type automatic level controllers are also used on vessels in this portion of the process.

One unusual instrument application is the Brown area meter which measures the flow of viscous paste from storage to the preheaters. This unit operates on the same inductance bridge principle described previously for the electric flow meter, but utilizes changes in area through a variable orifice with a fixed differential pressure as the basis for flow measurement. The meter-body, installed directly in the paste line, is steam-jacketed and connected to a locally mounted indicator (see Fig. 3) as well as to a board-mounted recorder in the main control room.

For the measurement of the paste pressure following the high-pressure pumps (prior to introduction into the paste preheater) an Ashcroft "Homogenizer" type pressure element is used. This element comprises a liquid-filled system with a closed-end tube connected to the conventional Bourdon tube. Pressure on the tube is transmitted to the Bourdon element by the liquid fill. Clogging of the usual pressure tap by the paste is thereby averted.

C—PASTE AND VAPOR-PHASE PREHEATERS

Paste from high-pressure steam-driven plunger pumps flows in series through the four cells of the paste preheater, where temperature measurement and control assumes paramount importance. On the exit side of the pumps, pressure in the paste line is recorded on a board-mounted instrument, which is equipped with a high-limit alarm switch for shutting down the pumps in the event an excessive pressure develops in the system. This is accomplished through an electric-pneumatic relay which closes the steam supply valve and opens a venting valve.

Temperature Measurements, Paste Preheaters (Fig. 5)

Flow-recorded recycle hydrogen is introduced in the paste line and the mixture is temperature-recorded at the inlet to the preheaters. Surrounding the paste tube inside the preheaters is a concentric outer tube into which is passed superheated steam at 400 psi. and 750 F. This steam receives added heat for the gas-fired burners in the preheaters and serves as a method of transmitting the heat without localized overheating of the high-pressure paste tubes.

The entering steam is both flow- and temperature-recorded by board-mounted instruments. Numerous thermocouples are located in the paste tube and in the steam jacket at critical tube-wall tem-

perature reading points, some of which are continuously recorded, while others are connected through pushbuttons to indicators for periodic checking. Other thermocouples, installed in the cell combustion chambers and flue outlets, are also connected to indicators to provide a check on firing of the gas burners, while the temperature in the common stack for the four cells is continuously recorded.

Temperature Control

The physical characteristics of the coal paste, such as viscosity and swelling effect, require that each stage of the preheating process be performed under carefully controlled optimum temperature conditions. To do this, the temperature at the outlet of each preheater cell is measured by a thermocouple which is connected to a board-mounted recording and controlling potentiometer (TRC in Fig. 5). This instrument, through actuation of a pressure-balanced diaphragm-motor valve, throttles the supply of fuel gas to the pair of burners in each cell. Total fuel gas consumption and the amount used in each cell are measured by separate locally-mounted recording flow meters.

To avoid coal swelling difficulties which would occur around 600 F., additional hot hydrogen and recycle heavy oil are added to the outlet of the first preheater cell where the temperature is about 570 F. In this manner the paste is jumped in temperature to around 640 F. and controlled at this value by regulation of the amount of recycle hydrogen flow by-passed around the E-1 heat exchanger used to cool the hot catchpot overhead product. This is accomplished by a throttling valve in the by-pass line under command of a potentiometer controller which measures the temperature of the paste after the hydrogen and heavy oil addition.

Vapor-phase Preheater

Instrumentation of the vapor-phase preheater is generally quite similar to the paste preheater with the exception that only one cell is involved. Indication or recording of the combustion chamber and process fluid temperatures is obtained in the same manner and control is provided from the outlet product temperature in an analogous manner.

As an auxiliary safety system, a high-temperature alarm contact on an electronic recorder for the process line within the preheater energizes an electric-pneumatic relay to close a diaphragm-motor valve on the fuel gas supply line in the event of excessive temperature of the stock.

D—LIQUID- AND VAPOR-PHASE CONVERTERS

To obtain 95 percent conversion of coal to liquid and gaseous products, the reaction temperature must be held at 930 F. Since the reaction is highly exothermic, it is necessary to cool the converters. This is accomplished by adding relatively cool hydrogen at different points in the vessels in controlled amounts. The flows of these cooling hydrogen streams are controlled from

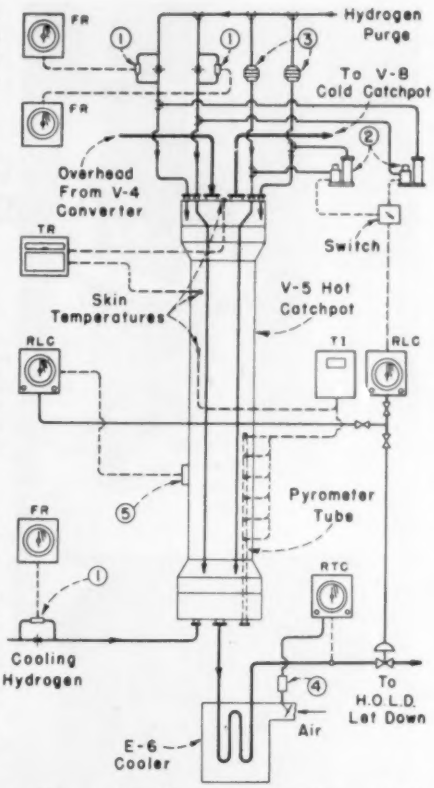


Fig. 9. Simplified Instrumentation of Hot Catchpot.

FR—electronic flow recorder; TI—electronic temperature indicator; TR—multi-point electronic temperature recorder; RTC—recording temperature controller; RLC—recording level controller; 1—Statham differential pressure element; 2—Brown high-pressure electric meter body; 3—capillary throttling tube coil; 4—pneumatic damper motor; 5—Gagetron sensing element.

temperature measurements taken downstream from the points of entry of the cool hydrogen to the vessel (see Fig. 8).

Temperature measurements within the converter are taken through a centrally-located seamless-steel pyrometer tube about 40 feet in length. This tube is installed vertically through the top of the converter and is held in place by several steel spiders. The tube has a closed bottom and a wall thickness of over an inch, being designed to withstand an external pressure of 10,300 psi. at 1,000 F. Inside this tube is an eighth-inch stainless steel pipe to which are attached six thermocouple elements at vertical levels of every six feet.

Three of these couples are connected to recording-controlling "ElectroniK" potentiometers (TRC's in Fig. 8) which maintain the desired temperatures in the converters by throttling the supply of cooling hydrogen through actuation of diaphragm-motor valves A, B, and C. The other three couples are connected through pushbuttons to an indicating instrument and serve as a means for periodic checking of other points in the converters.

Since the alloy steel shells of the converters cannot exceed an operating temperature of 500 F, it is important that shell temperatures at several points be known at all times. Three skin thermocouples, located at representative points along the vertical height of each converter, are connected to indicating and recording potentiometers and thus serve as important safeguards to these pieces of equipment.

Cooling Hydrogen Flows

To continually make certain that cooling hydrogen is being introduced at each of the three entry points in the converters, these hydrogen flows are measured and remotely indicated on the main instrument control panel. Any impedance of these flows would unbalance the conversion reaction.

The flow of hydrogen in each line is comparatively small, ranging from 70 to 100 cfh. To measure these small flows, a special Statham measuring element was designed. This comprises a vane which is rotated by the flow of hydrogen. An Alnico magnet attached to the vane shaft rotates with the vane, developing an alternating current which is converted to d.c. and fed to a Weston indicating milliameter, calibrated in terms of flow (FI in Fig. 8).

The total flow of cooling hydrogen to each converter is measured and recorded by means of a Statham differential type flow meter (FR) previously described.

Vapor-phase Converter

Instrumentation of the vapor-phase converter is quite similar to that for the two liquid-phase converters. Five zones of temperature control by means of streams of cooling hydrogen are established in the catalyst beds under the command of separate "ElectroniK" recorder-controllers, identical in application to those in the liquid-phase converters. In addition, however, a narrow-range (850 to 900 F.) electronic controller is installed on the converter inlet line from the preheater to control this critical temperature by regulating the injection of cooling hydrogen into the inlet line.

Important internal temperatures in a pyrometer tube (of the design previously described), and skin temperatures of the vapor phase converter, are logged on board-mounted electronic multi-point recorders. These provide a valuable check on the operation of the unit.

E—HOT CATCHPOT

Measurement and control of the heavy oil level was probably the most difficult instrumentation problem to solve in connection with the hot catchpot. (See Fig. 9.) Should the level in this vessel go too low, all pressure in the system would be lost; should the level rise too high, failure to make separation of the lighter hydrocarbons and hydrogen from the heavy oil would occur. Because of the importance of level control at this point, much effort was devoted to the problem. In fact, two methods of measurement are employed and arranged so that either can be used to control the level.

Some of the factors which contribute to measurement difficulties include: (1) the heavy oil contains ash and other entrained solids which tend to cause plugging of some types of measuring elements; (2) the oil is saturated with hydrogen; (3) the variation in head is

comparatively slight: about two feet of liquid, as compared with a total pressure on the vessel of about 10,000 psi. Insofar as level control is concerned, this problem was made difficult because of surges which carry over from the converter.

Differential Pressure System

In this arrangement, a Brown high-pressure mercury manometer (2 in Fig. 9) measures the differential pressure between two hydrogen purge lines. One line is connected to the upper (vapor) space of the catchpot; while the outlet of the other line, which passes vertically down through the liquid, is located slightly less than two feet above the bottom of the vessel. It is desired to maintain the level about five feet above the bottom of the vessel.

Equal flows are maintained in both purge lines so that the pressure difference is due only to the liquid head in the hot catchpot. The flows of hydrogen through these tubes must also be sufficient to prevent asphalt from creeping back into the lines. The purge lines are also equipped with orifice plates for flow recording by means of Statham elements (1 in Fig. 9).

Level readings are transmitted electrically to an electronic recorder pneumatic controller located on the main instrument control panel. This latter instrument automatically controls the heavy oil level by throttling the flow of heavy oil through a diaphragm motor valve located on the heavy-oil outlet line following cooler E-6. This instrument is also equipped with high- and low-level alarm switches.

A duplicate pair of hydrogen purge lines is also installed and connected to a separate electric flow meter body. Electrical connection of the level controller can be switched to either meter body so that measurement is assured at all times, in case difficulty with one system arises. Uniform flow in the latter pair of purge lines is accomplished by a capillary throttling tube coil installed in each line. The choke effect of these capillary coils is not affected by the small pressure variations caused by hydrogen feed line resistance.

"Gagetron" System

The second method of checking and alternately controlling the above level is accomplished by a Geiger-Mueller detector, known as the "Gagetron," which is installed on the outside of the vessel (5 in Fig. 9). This unit* detects gamma rays emitted by a radium salt contained in an iridium-platinum needle mounted on the pyrometer tube located inside the vessel. The gamma-ray absorption properties of the heavy oil differ sufficiently from the absorption by the vapors and gases in the vessel for this device to serve to detect the heavy-oil level. This type of measurement is not influenced by changes in temperature, pressure, or chemical composition of the fluids in the vessel.

The output of the "Gagetron" is amplified and electrically transmitted to a Brown electronic recording controller located on the main instrument control panel. Hand valves in the control air lines from the two level controllers are provided so that either can be used to operate the controlled valve. Fig. 10 shows the "Gagetron" sensing element mounted on the side of the hot catchpot.

*Manufactured by Engineering Laboratories, Inc., Tulsa, Okla.

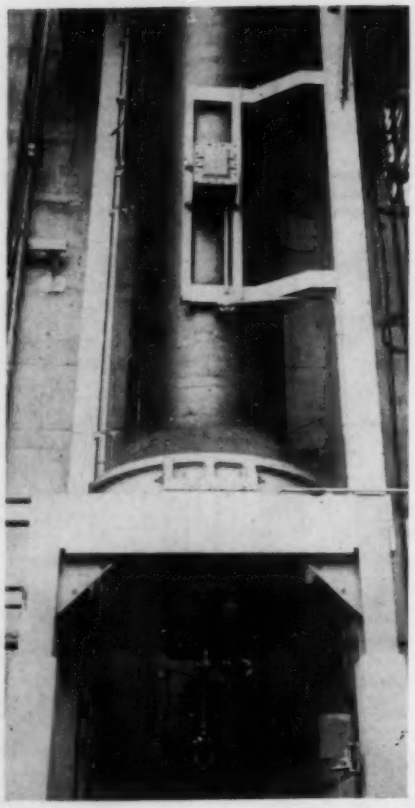


Fig. 10. View of hot catchpot, showing "Gagetron" installation top center and , at bottom center, pyrometer tube containing thermocouples.

Temperature Measurement and Control

A pyrometer tube similar to that used in the converters is also employed in the hot catchpot. In this vessel, the tube extends from the bottom to about two feet above the top of the liquid. Six couples are vertically spaced along the tube at one-foot intervals. They are connected through pushbuttons to a board-mounted "ElectroniK" indicator.

Hot catchpot bottoms must be cooled to approximately 375 F. before let-down (pressure relieved) to subsequent vessels. Cooling is accomplished by blowing ambient-temperature air over a series of hairpin coils. Proper temperature control is of importance to prevent solidification of the heavy oil. A thermocouple measures the temperature at the heavy-oil outlet from the cooler. This couple is connected to an electronic temperature recorder-controller which pneumatically positions a damper on the air inlet line to the cooler. (see Fig. 9.)

The cooled catchpot bottoms pass to the heavy-oil let-down tank where the liquid level is measured and controlled by a Fisher displacement type automatic controller. Light gases pass out from the top of this vessel to the fuel gas system. The flow is measured by a manometer type meter and recorded. A back-pressure regulating valve holds the pressure in the fuel gas supply line at the proper value.

F—COLD CATCHPOTS AND ASSOCIATED EQUIPMENT

Liquid level is the only variable of major significance in operation of the cold catchpot for the liquid and vapor phases. Level is indicated by a special Penberthy high-pressure transparent gage and is controlled by a Brown recording level controller equipped with high- and low-level alarms.

Normal operating temperatures are 150 F. in the liquid-phase catchpot. Temperatures of the two cold catchpot bottoms are measured and indicated on the main control panel.

Naphtha is injected into the top of the liquid-phase cold catchpot. Its flow is recorded; and it is controlled by regulation of steam supply to the injection pump. The naphtha provides sufficient difference in specific gravity of the catchpot bottoms to permit proper interface level control in the subsequent V-9 let-down drum.

Instrumentation of the wash oil scrubber employs a liquid level control instrument of the same type used on the cold catchpot which it follows in the liquid-phase process. In addition, flow of wash oil, injected into the scrubber through the top head, is held constant by a recording flow controller operating a valve on the steam supply to the injector pump.

In both the liquid and vapor phases, the compressor suction traps must operate properly to insure that no liquid passes on to the hydrogen recycle compressors. This function is guarded by non-indicating high-level alarms on the traps. These controls utilize a Statham differential pressure element connected to special Brown electronic relays which energize visible and audible alarms should the level in the traps rise above preset maximum values.

The material balance of hydrogen recycled in the liquid and vapor-phases is maintained by Brown recording pressure controls installed on purge lines to the fuel gas system.

The Hydrogenation Process

(Concluded from page 571)

sures for level and flow-rate control at 10,000 psi.

During construction it was found that neither the average American manufacturer nor the construction forces realized fully the severity of the service in a coal-hydrogenation plant. In numerous instances, flaws in materials and unsatisfactory workmanship were not brought to light until after shop tests, or even after delivery to the job site. As construction progressed, improvements in process and design were developed. In addition, manufacturers gained considerable knowledge in high-pressure design and fabrication methods—a long step toward preparing them for building full-scale plant equipment.

(Verbatim extracts from an official release by the Bureau of Mines.)

BEGINNING another important *Instruments* serial—presenting for the first time a wealth of information by an outstanding authority on the automatic control of industrial processes. Mr. Chaplin not only discloses a large number and wide variety of successful solutions of control problems that had stumped other experts, but explains in detail the reasons: the BASIC PRINCIPLES.

After writing the above (and we assure you it's no exaggeration) we must mention one minor point of disagreement. For years we have preached that "you can't control what a condition WAS" and crusaded in favor of faster and faster measuring elements. Firm in our stand, we oppose "increasing detection lag"—which Mr. Chaplin recommends (fortunately in small type and for only one case of the equilibrium lag problem) on page 609. Yes, we asked him and he stated his case eloquently—but we think this problem could be solved in a better way.—MFB

Some Application Factors Affecting *the* Regulation *of* pH *in* Industry

By ALLEN L. CHAPLIN, Consulting Engineer

TO the process control engineer the problem of industrial pH regulation is unique because it departs sharply from conventional techniques of regulating physical variables such as velocity, pressure, temperature, liquid-level, etc., which follow the laws of linear control. pH is a *concentration* variable which responds to and is a measure of the effects of a chemical reaction; and, like most concentration measurements which respond to or are a result of chemical reactions, it follows a non-linear control relationship. It is characterized by high rate of reaction and non-linear reversal in rate response.

This serial covers some problems of APPLICATIONS as affected by the theoretical concepts and as experienced by the writer in the application of pH control in industry. Some theoretical conditions are first presented in an introductory manner.

THEORETICAL REVIEW

In reviewing the theoretical aspects of pH control, we find wide variations in the behavior of different processes depending on the nature of the material processed and the way in which pH enters into the chemical reactions. The rate of reaction varies with different processes from practically instantaneous, upwards to several minutes, and the degree of non-linearity ranges from sharply peaked curves through rolling characteristics to practically straight lines, which, for all practical purposes, behaves similarly to a temperature control process. If pH enters into the reaction directly, as in the neutralization of strong acid or alkali, the reaction rate is high and is characterized by sharp-peaked reversals at the equivalence point. If its reaction is indirect to establish a medium for precipitation of other reactions or delayed flocculations or setting of gels starches, resins, etc., the rate is comparatively low and variable, and the *acidity characteristic* is characterized by hysteresis due to occlusion and other effects which buffer the rate change as described in the following chapters (see Figs. 12, 16 and 17).

The quantitative relationship of the important variables affecting pH is given elsewhere but some definitions are given here for clarification of the discussions to follow.

A—CONTROL RATE CHARACTERISTIC

The control rate characteristic is essentially a measure of the rate-response of a process to incremental changes in reagent addition. It defines the controllability of a process at various settings of the controller index and under various conditions of load. It is characteristic of all pH processes but an individual derivation must be made for each process considered. Each process has its own characteristic control rate which applies to it specifically under the conditions of which the data were derived.

Fig. 1 is a typical control rate characteristic of the acidification of industrial process water using 0.0024 N sulphuric acid as the control reagent. It is to be noted that the rate of pH change per unit of reagent addition is greater at one

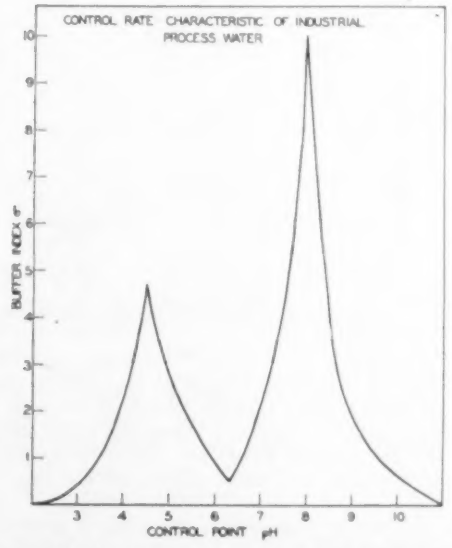


Fig. 1. Control rate characteristic of a pH control process. Buffer index describes sensitivity of process or its response to reagent addition.

pH value than another and, consequently, the proportional band setting of the control instrument cannot be uniform for all settings of the controller index. At 8.0 pH, the control rate rises steeply and reverses abruptly, thus indicating an unstable process quite difficult to control at this point. A second peak occurs at 4.5 pH and, although it is approached more gradually than the first, it rises above a threshold limit (buffer index = 1) and represents comparative instability of regulation.

A process of the type characterized by Fig. 1, operating at 8.0 pH would require an extremely fast control action operating in a system of zero capacity and zero response lags to maintain close regulation. The rate of reaction is of the order of one second and the regulator would be required to measure the pH change, balance in and be capable of

full-stroking the valve and delivering the regulated water to the electrodes in less time than is required for the chemical reaction to reach completion. The same condition applies to all direct-reaction high-rate pH processes in general, but the impracticability of this condition is that regulators for industrial application have not been built with such characteristics. As a practical expedient, it is customary design practice to weight the process with inertia and residence to damp out the magnitude of load changes and reduce the rate-charge. In a sense, this is paradoxical since the introduction of sufficient capacity into the process to reduce its rate response to that of an inadequate regulator, introduces another variable, namely *equilibrium lag* which is discussed in the following chapters.

If a proportional-position regulator were applied to the characteristic illustrated in Fig. 1, and adequate capacity introduced to reduce load swings, an exceptionally wide

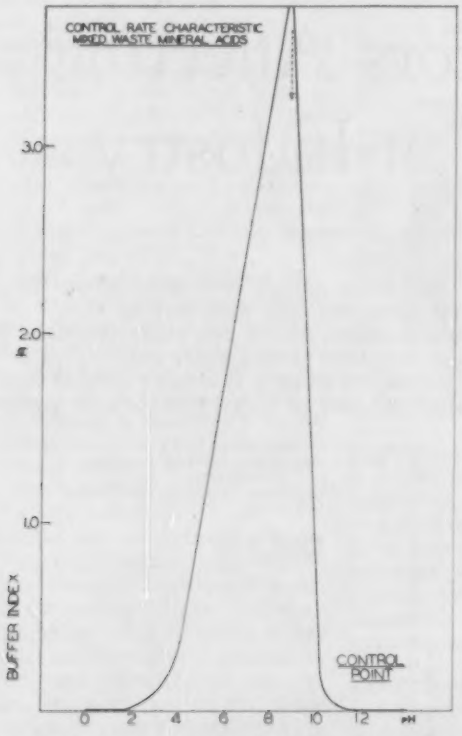


Fig. 2. Control rate characteristic of pH control process. Neutralization of waste mineral acids.

proportional band setting would be required to avoid overcontrol. Moreover, this setting would be so wide that the proportional action would be unresponsive to normal load swings and the process would be dependent wholly upon its own residence and the reset action of the regulator for control.

If the process of Fig. 1 were operated at any pH control point corresponding to a buffer index of 1.0 or below, it would be comparatively easy to regulate with conventional controllers since the rate response of the process in this range is more nearly matched to that of the regulator: Load swings are not so pronounced and the process responds gradually rather than abruptly.

It is a common fallacy of thought that pH is most difficult to regulate at neutrality, namely 7.0 pH. This is true only with pure water since the actual control rate characteristic is wholly dependent upon the nature of solute and composition of the process liquor. It is certainly not true of Fig. 1 nor most other industrial processes with which the writer has had contact. Buffering action may vary from one end of the pH scale to the other depending on the nature of the solution and it is not uncommon to find reactions more strongly buffered at 7.0 pH than at other points on the scale. A batch neutralization process will be described later (Fig. 50) which is strongly buffered at 7.0 pH and requires more than 80% of the total reagent addition to change pH from 6.8 to 7.2.

Fig. 2 is the control rate characteristic of another chemical reaction, namely the neutralization of waste industrial nitrating acids. It is characterized by a single peak which reaches a maximum at approximately 8.4 pH. Other characteristics may have three or four peaks with heights varying from rolling nubs to sharp spears, each individually characteristic of a given process.

The significance of the non-linearity of a pH control rate characteristic becomes apparent when compared with the comparable relationship of a linear temperature control system. Fig. 3 is a plot of the rate characteristic of a temperature system and is generally descriptive of all temperative systems if the effect of heat application to the process results in purely physical changes not attended by chemical reactions or a change in state of aggregation or other similar conditions of molecular rearrangement which brings about a change in specific heat. A temperature rate characteristic is usually a uniform straight line parallel to the abscissa and differs from similar characteristics of other temperature systems by displacement up or down along the ordinate axis.

Some temperature processes are characterized by gently sloping or slightly curved plots or sharp breaks in slope of

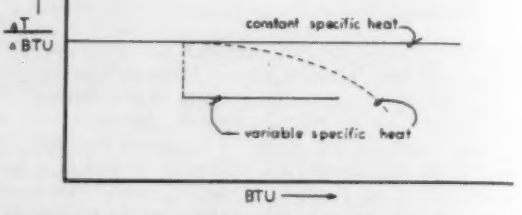


Fig. 3. Control rate characteristic of typical linear temperature control process. Compare with Figs. 1 and 2.

the curve when a molecular rearrangement results from heat application and changes specific heat of the medium as illustrated in Fig. 3. They are not usually possessed of the sharp hill-and-dale reversals of a pH process. The rate change is independent of load and a regulator may be operated at fixed sensitivity over a wide range, whereas the sensitivity of a pH regulator must vary with load or be otherwise compensated.

The control engineer will recognize the similarity of a pH control rate characteristic and the standard "capacitance" term adopted by the A.S.M.E. terminology committee to define process rate of reaction. They are inverse functions except for the typical reversals of a control rate characteristic.

The coördinates of the temperature rate characteristic are self-evident and have been fixed by standard definition. The ratio of incremental change in temperature per increment of Btu. input is related to specific heat and is based on universally accepted standard definitions.

The comparable rate increment of a pH characteristic is not based on standardized and accepted definitions; and the writer has found it necessary to derive a function which describes the ratio of incremental change in pH per increment of reagent addition. This ratio has been defined as the *buffer index* of the solution.

B—Buffer Index

Buffer index may be defined in a number of ways depending upon one's theoretical approach. It may be defined as a dimensionless ratio of pH change resulting from a given increment of reagent to the theoretical change which would result by the addition of the same increment of reagent if the solution were completely ionized. This definition has theoretical merit but little practical value since it usually is not possible or desirable to determine the exact ionic behavior of industrial process liquors. Furthermore, the conditions of test do not necessarily remain constant from day to day. It is difficult to derive a definition readily applicable

to the analysis of all control applications since each individual process has a specific acidity characteristic requiring individual treatment. Furthermore, because of the individuality of pH control processes, it has been found desirable to derive a definition based on its application to graphical solutions of control problems.

The writer has adopted a definition for buffer index as being *"the incremental change in pH resulting from the addition of one milliequivalent of reagent to one liter of process liquor."* It is designated as the ratio

$$\frac{\Delta \text{pH}}{\Delta \phi} = \sigma \qquad (1)$$

or more simply referred to by the Greek symbol (σ). Phi (ϕ) is the number of milliequivalents of control reagent per liter of process liquor, corresponding to a given pH change.

The practical merit of this definition is that quantities are additive and the total reagent requirements and valve sizes may be calculated directly from the buffer index data. The control engineer may have preference for an expression of buffer index in terms of gallons of reagent per gallon of process liquor or gallons-per-minute flow of reagent per gallon-per-minute of process liquor required to maintain control; or it may be desirable to determine how much deviation in pH from the set point will result from the addition of a given increment of reagent to a particular process. This information is important and although the above buffer index definition has been adopted for the purpose of mathematical derivations, it may be converted, by appropriate conversion factors and standard engineering terms required for analysis of process behavior and application of the method to process design and selection of the appropriate mode of regulation.

It is not always possible to obtain buffer index data of a new process since the regulator is specified and ordered in many cases before the process is put in operation. The above control rate concept of analysis requires individual determinations of buffer index and control rate for each process involved and falls down unless this data can be provided. However, it does have practical merit and becomes more useful as data are derived from processes to which it has been applied: A cumulative index of control rate characteristics of many representative applications makes it possible to establish a basis for design and application of equipment for various standardized applications.

Buffer index data derived from the above concept not uncommonly yield values of 10 and above whereas an unclassified physical analysis of an actual acidity characteristic of pure water may indicate that such values are impossible. It must be borne in mind that the buffer index ratio is an instantaneous value corresponding to the point of tangency at the desired control point on the acidity characteristic curve (to be described later). The fundamental purpose of buffer index is not to define the axact magnitude of pH change resulting from a given volume of reagent addition but rather to establish an index of rate-of-change at the control point. The magnitude and rate will both change with variations of the set point and they correspond exactly only at infinitesimal values of

$$\frac{d\text{pH}}{d\phi} = d\sigma \qquad (2)$$

As the increments become larger, the deviation of magnitude and rate becomes larger by virtue of the buffering action and ionization characteristics of the process liquor. Both values are important criteria to process design and regulator application. Magnitude may be derived from the acidity characteristic and is of importance in selecting the required residence for process design. Rate change also has bearing upon the process residence but is most important in design and selection of the regulator.

A threshold limit of buffer index may be established for a given type of regulator applied to a given process. For example, the rate response of certain commercial pH regulators of the proportional-position type have time constants which render them best applicable to processes having a buffer index of 1.0 or below. Still other commercial regulators of the proportional-speed floating type have much lower time constants, more in keeping with the requirements of the pH variable, and have been successfully applied to regulate, within close limits, processes having a buffer index of 3.0 and 4.0, and with less residence capacity than is required by the proportional-position type; although the proportional-speed floating regulators may require supplementary stabilization. Proportional-position plus derivative regulators have extended the threshold limit of conventional proportional-position regulators to a buffer index of 5.0 and above for a given residence, but this mode of regulation is usually best applied to processes having delayed residence reaction or delayed detection of control changes.

C—Acidity Characteristic

The acidity characteristic is essentially the *fingerprint* of a pH control process and it supplies the necessary data for derivation of the foregoing control rate characteristic and buffer index values. It reveals the exact theoretical behavior of the process at any desired control point, and predicts the magnitude of pH deviations either side of the control point. The general shape of the acidity characteristic

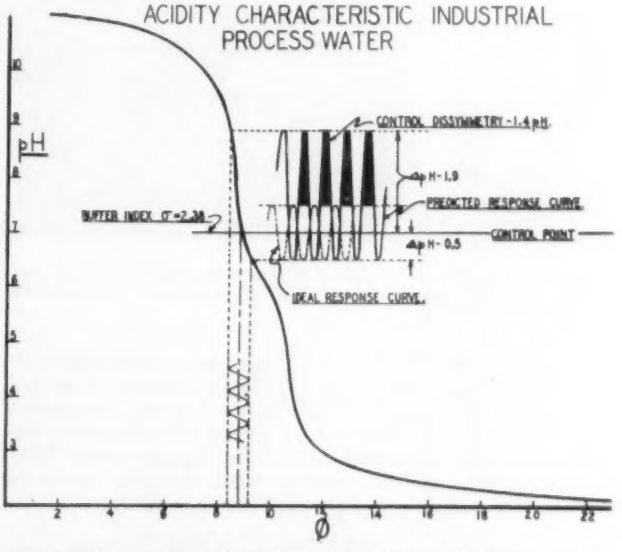


Fig. 4. Acidity characteristic of pH control process. Illustrating graphic method of predicting general behavior of process at control point under conditions of changing load or throttling reagent feed.

is a typical "S" curve but the exact form may vary from a gently rolling curve with gradual slope to an abrupt, steep break, depending on the nature of the process.

The acidity characteristic may be used to predict what changes in pH will result from a given valve movement, or, conversely, what valve movement is required to obtain a desired pH change. The curve is derived by plotting measured pH resulting from known additions of control reagent to a liter of process liquor.

Fig. 4 is the acidity characteristic of the process defined by the control rate characteristic of Fig. 1. It refers to the acid neutralization of an industrial process water containing sodium carbonate and organic matter. The important point to note on this curve is its unsymmetrical shape which reflects directly upon the asymmetry of the actual control record obtained at any selected control point, and a given throttling range of the valve. For example, the actual control point of the process represented, is 7.0 pH, which, according to Fig. 1, would have a rate response equal to buffer index 2.0. A throttling range corresponding to 1.0% change in reagent addition at pH 7.0 would theoretically produce a control dissymmetry of +1.4 pH. In other words, a pH recorder-controller should produce an unsymmetrical control record having frequent upscale excursions of the pen by a difference amount equal to 1.4 pH. This may be determined graphically by projecting a given valve throttling action from the X-axis, through the acidity characteristic curve to the y-axis as illustrated in Fig. 4.

An actual recorder record of this pH control process is

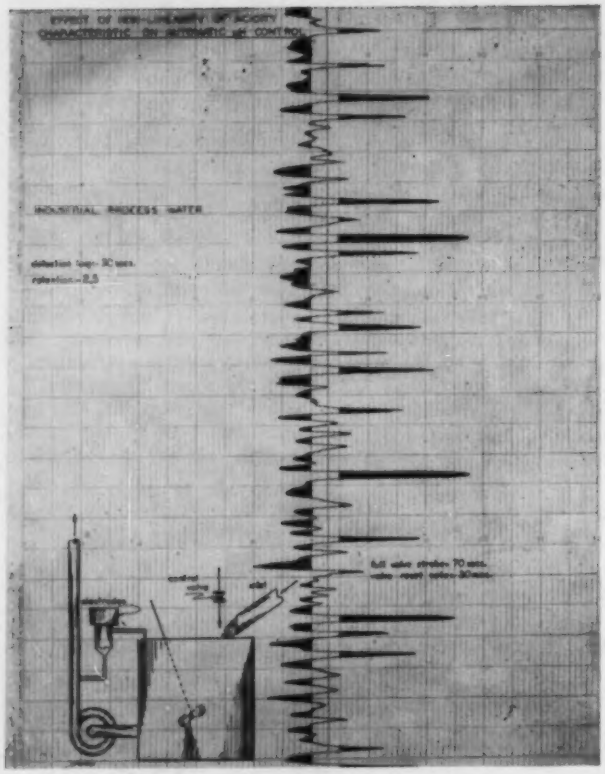


Fig. 5. Actual pH control record of process described by acidity characteristic Fig. 4. Showing agreement of actual control and results predicted graphically from Fig. 4.

illustrated in Fig. 5. It is important to note that, notwithstanding other conditions pertaining to inadequacy of control equipment, which will be discussed later, the process behaved exactly as predicted by the acidity characteristic. The irregularity of actual upscale excursions is due to inhomogeneity in the processing vessel brought about by equilibrium lag and uncontrolled short-circuiting* of the vessel.

The acidity characteristic of one type of high-grade paper stock is illustrated in Fig. 6. The control reagent is sodium aluminate which introduces a "fold-back" or double buffering action and causes a double inflection in the characteristic curve. It is evident from this curve that the process is most highly buffered in the range of the first "flat" between 4.25 and 4.5 pH, and the process would be most stable in this range if load fluctuations did not exceed these limits. Should the control point be at 5.0 pH or 4.0 pH, at the break point of either "hump," an unsymmetrical control record would be obtained. At 5.0 pH, the pen would make periodic upscale excursions whereas at 4.0 pH it would make periodic downscale excursions.

Ordinarily, the buffer index of paper stock is well below the threshold limit 1.0 for proportional position regulators and there is little difficulty encountered in control providing other important factors are accounted for. Fig. 7 is an actual record of control at 6.0 pH, of the process represented by Fig. 6. It is to be noted that except for other irregularities the process behaves as predicted by the acidity characteristic.

A second high-grade paper stock is represented by acidity characteristic, Fig. 8. The general slope of this characteristic is negative, resulting from the acidic reagent, whereas the previous one is positive owing to the alkaline control reagent.

In general, the characteristic of paper stock are gently rolling curves and the buffer index rarely exceeds 0.5. So far as the chemistry of control is concerned, it is not a difficult pH problem and any inconsistencies of regulation are usually the result of physical variables in the process.

Some processes have peculiarly-shaped acidity characteristics showing reversals in trend due to complex chemical reactions which take place between the reagent and process liquor or between individual constituents of the liquor at some optimum pH value. Fig. 9 is a characteristic of such a process wherein anhydrous ammonia is reacted with a primary reagent to form an intermediate product. Feed of ammonia is regulated by a pH controller set to maintain a slight ammonia excess at 9.0 pH.

It would be desirable to control the process at its exact stoichiometric end-point but the characteristic passes through a minimum or "fold back" at this point and the regulator would lose control because valve movement in either direction results in an *increase* of pH.

The buffer index reaches an extremely high value at 9.0 pH, namely 33.3, and it became necessary to recycle much of the controlled effluent and use cascaded regulators to obtain any acceptable degree of stability. This method will be described in a later chapter.

It is an interesting study to follow the course of the chemistry involved in Fig. 9. First the addition of ammonia forms a complex compound which buffers pH changes very strongly between 7.5 and 8.5 pH. Beyond a phi value of 9.0, further ammonia additions result in a *decreasing* pH which reaches its limit at $\phi = 11.3$, after which the pH continues upward. Characteristics of other processes have been observed having similar fold-backs.

In analyzing a process for design and application of pH control, it is frequently desirable to run a family of acidity characteristic curves, covering the load ranges from minimum to maximum, to determine whether the buffer index

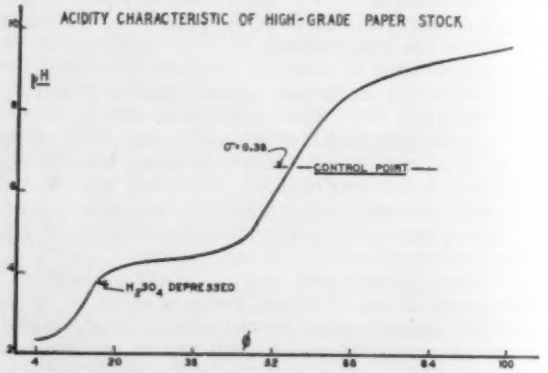


Fig. 6. Typical acidity characteristic of high-grade bond paper stock. Gentle rolling curve general characteristic of paper stock. Double inflection characteristic of sodium aluminate reagent.

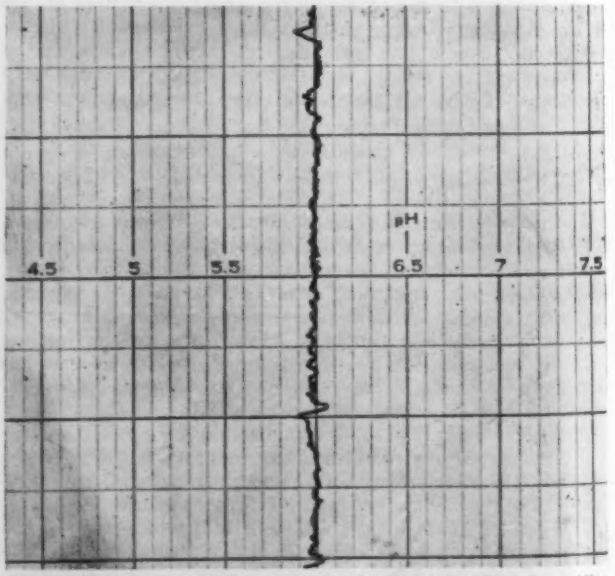


Fig. 7. Record of control at 6.0 pH of process described by acidity characteristic Fig. 6.

*Short-circuiting of a reaction vessel is standard terminology of chemical engineering to denote the portion of influx flow which passes out with the effluent stream without completely reacting with tank contents. Short-circuiting is reduced by agitation but is also a function of reaction rate and cannot be eliminated entirely.

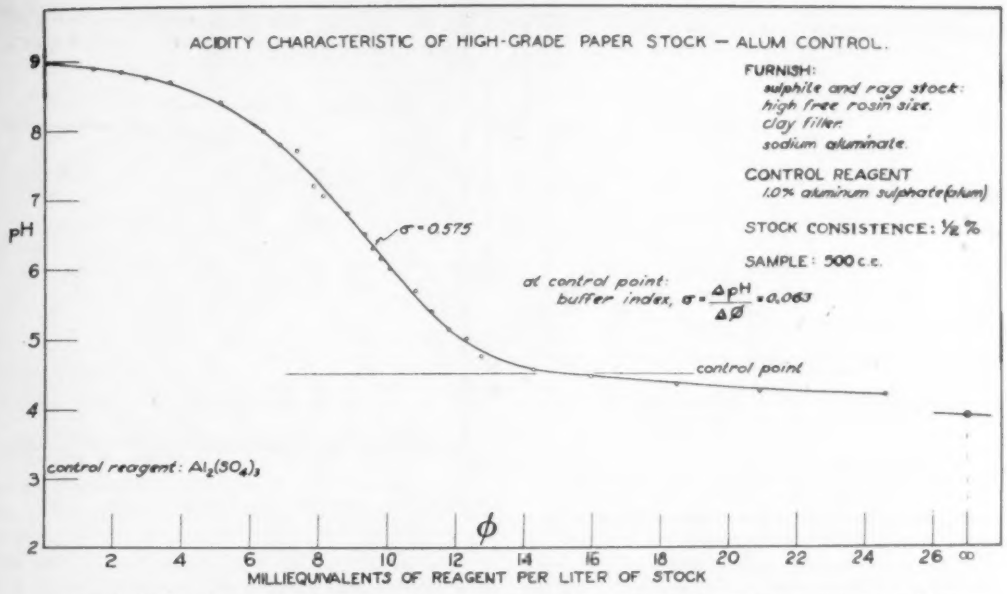


Fig. 8. Acidity characteristic of high-grade bond paper stock, showing gentle rolling characteristics and low buffer index at control point. Acid control reagent gives negative slope whereas alkaline reagent of Fig. 6. gives positive slope to characteristic.

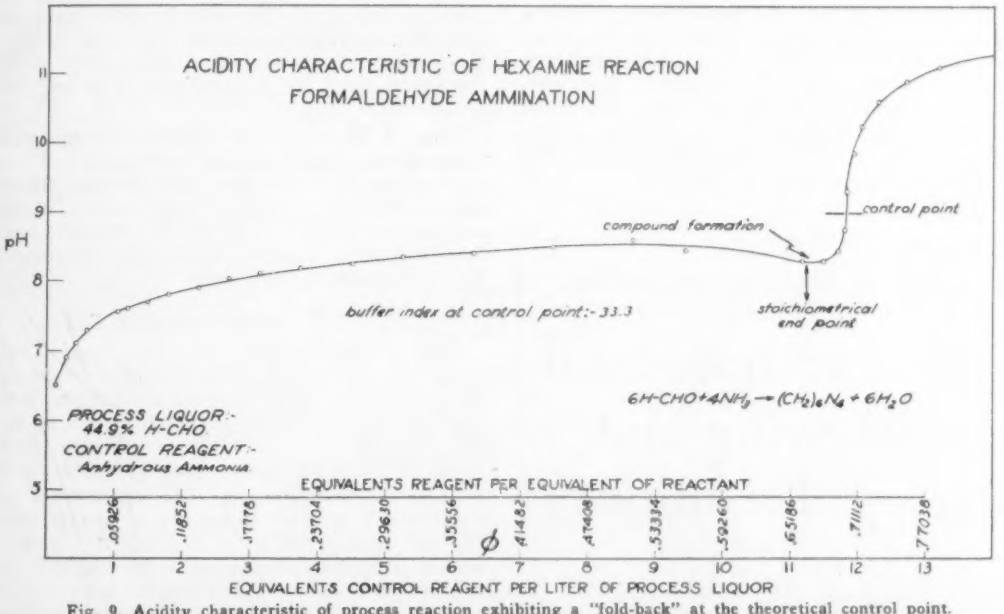

ACIDITY CHARACTERISTIC OF HEXAMINE REACTION
FORMALDEHYDE AMMINATION
compound formation
control point
buffer index at control point:- 33.3
stoichiometrical end point
6H-CHO+4NH3 → (CH2)6N4 + 6H2O
PROCESS LIQUOR:- 44.9% H-CHO
CONTROL REAGENT:- Anhydrous Ammonia
EQUIVALENTS REAGENT PER EQUIVALENT OF REACTANT
pH
EQUIVALENTS CONTROL REAGENT PER LITER OF PROCESS LIQUOR

Fig. 9. Acidity characteristic of process reaction exhibiting a "fold-back" at the theoretical control point. Process cannot be controlled at this point, thus necessitating shift of control point to stable region carrying slight excess reagents.

shifts with load. Fig. 10 represents a typical plot of the load curves of a process having a relatively high buffer index which is constant over the entire load range.

The importance of this test is to determine whether a possible shift in buffer index would result with changing pH load of the influent at constant throughput. It has not been uncommon in the writer's experience to observe pH control installations which behaved very erratically at one ph load* yet were very stable at another load value. The cause of this condition was found to be a "wild" buffer index which varied with pH load.

There is an extremely important corollary between the magnitude of buffer index and its stability with pH load,

*pH load refers to the difference in pH of the unregulated influent stream and the regulated effluent stream. It represents the error which the regulator must correct.

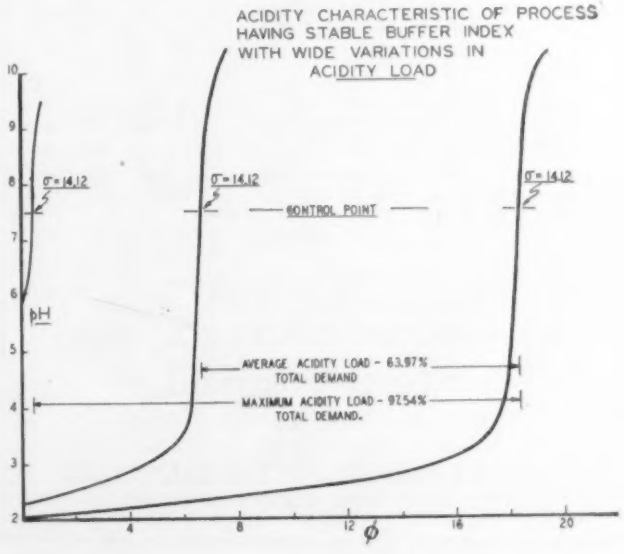

ACIDITY CHARACTERISTIC OF PROCESS HAVING STABLE BUFFER INDEX WITH WIDE VARIATIONS IN ACIDITY LOAD
σ = 14.12
σ = 14.12
σ = 14.12
CONTROL POINT
pH
AVERAGE ACIDITY LOAD - 63.87% TOTAL DEMAND
MAXIMUM ACIDITY LOAD - 92.54% TOTAL DEMAND.

Fig. 10. Acidity characteristic of chemical process. Illustrating method of determination of load behavior of process. pH load determined by projecting reagent requirements of maximum characteristic onto nominal load curve and reading corresponding pH values. For example 6.6 milliequivalents = 7.5-2.3 pH = 5.2 pH load nominal.

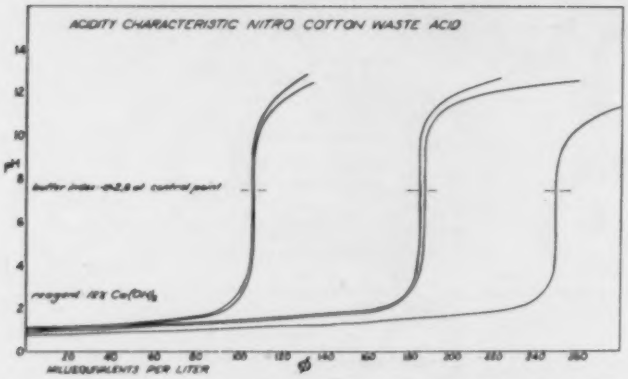


Fig. 11. Acidity characteristic load curves of waste acid pH control process.

and the nature in which pH enters into the chemical reaction. It has been the writer's observation that neutralization reactions or direct unbuffered processes attended by a high reaction rate, have high buffer index values but the index is comparatively stable and independent of pH load. Indirect pH reactions or processes having buffering action are usually characterized by a low buffer index which varies with pH load. There is a theoretical reason for this, but the practical aspects are important from an application viewpoint. Fig. 11 is a family of load curves representative of a direct neutralization process having a relatively high reaction rate, and large pH load: The buffer index is constant over this entire load range. Fig. 12 is an acidity characteristic representative of another process having a slower reaction rate but greater buffering action due to the formation of ferric hydroxide complex which gels and flocculates: The buffer index is lower but varies with pH load.

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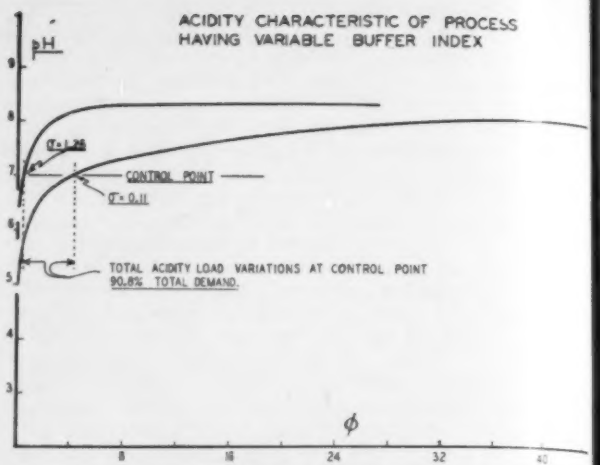


Fig. 12. Acidity characteristic of process exhibiting variable buffer index at the control point with load changes.

The conditions of high buffer index and variable index are both serious limitations to good pH control but by act of providence they are counteractive forces and rarely occur together in the same process. A variable index has never been observed above 1.3 by the writer, and, should it occur below index 1.0, the threshold limit for good regulation with proportional-position control, it is of little consequence. However, when a variable index is encountered between the limits of 1.0 and 1.3 or above, it is the source of no end of trouble.

Figs. 13, 14 and 15 show additional acidity characteristics presented as evidence of the individuality of each pH control application. Few processes have similar characteristics except in the high or low buffering range of single constituent electrolytes; and one process may present idiosyncrasies not encountered in another. An acidity characteristic is truly the fingerprint of its process.

D—Equilibrium Lag

Equilibrium lag in a pH control process is a manifestation of inhomogeneity brought about by physical or chemical conditions which prevent chemical reactions from reaching stabilized completion before leaving the process. The cause may be mechanical, physical or chemical, but the result is the same on the quality of control obtained.

Chemical reactions vary in rate from practically instantaneous for neutralizations of strong mineral acids to several seconds and even minutes for certain indirect reactions such as flocculations, gelations, etc. Some reactions are not reversible while others do not react with the same velocity in both directions and if the residence system in which these reactions occur is not homogenous, the output will be erratic. Precipitates and flocs occlude reagent within their structure and it escapes non-uniformly into the system, thus causing a false equilibrium. Fig. 16 is an acidity characteristic of one process containing equilibrium lag due to liberation of CO_2 by reaction of the reagent and process

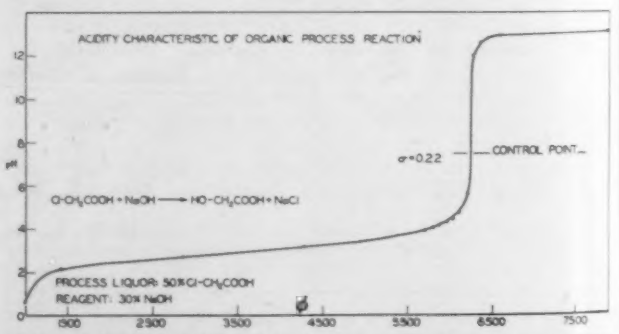


Fig. 13. Typical acidity characteristic of chemical process showing extreme buffering effect in lower and higher pH regions. Reaction typical of weak acid and strong base.

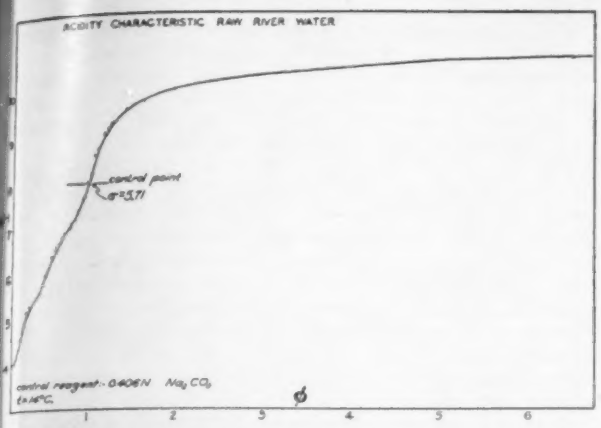


Fig. 14. The acidity characteristic of a chemical process is as exclusively representative of one specific process as fingerprints are of an individual.

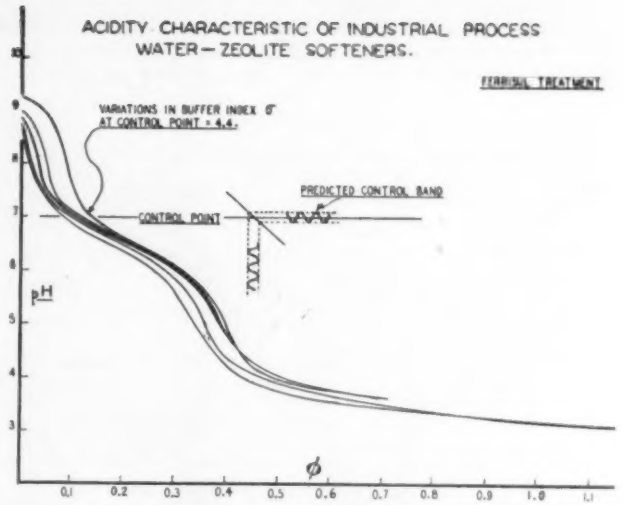


Fig. 15. Acidity characteristic of process exhibiting variable buffer index but narrow control band (0.25 pH) at control point 7.0 pH.

liquor. A pseudo-equilibrium exists between pH 4.0 and 6.5 which requires more time to equalize than the residence time of the process permits. The result of this condition is to cause either a higher equilibrium pH than the controller indicates if the system has ample residence, or an erratic regulated effluent stream if the process has low residence.

This type of equilibrium lag requires time and uniformity to equalize and the customary application practice is to either design the control system with residence time greater than the required equilibrium time or to use two cascaded pH controllers in a low residence system with enough velocity-distance separation to permit equalization. Fig. 17 is another illustration of the same type of equilibrium lag which must be treated in the same way as the above process.

This type of lag requires time to establish equilibrium and it must be treated in control analysis conversely to detection lag. If the buffer index is low, the electrodes may be separated a distance from the control valve with satisfactory results. If the buffer index is high, the system requires high residence or cascaded control on low residence.

A commonly recognized form of equilibrium lag is poor agitation. Without knowledge of the mechanism of agitation or its relationship to residence and short-circuiting, many control engineers recommended "plenty of agitation and large tanks" as the cure for all pH evils. There is an optimum relationship wherein the tank contents must be "turned over" sufficiently to reduce short-circuiting to its point of maximum gain and any expenditure of agitation power beyond this point is a sheer waste of money. If the tank is made larger, the power required to reduce short-circuiting goes up as a cube function and it has been found

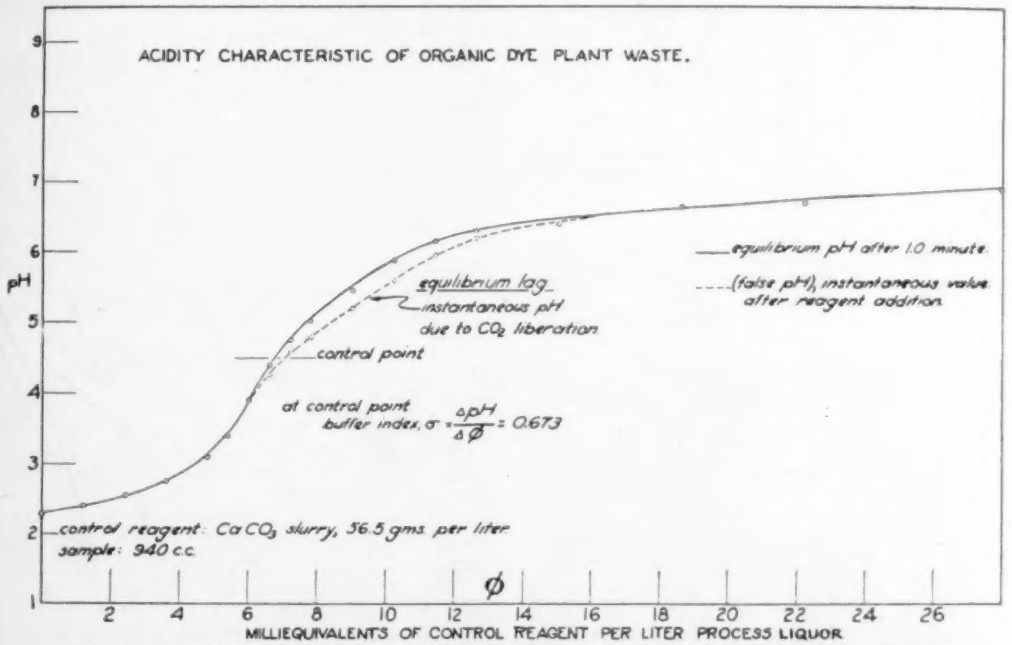

ACIDITY CHARACTERISTIC OF ORGANIC DYE PLANT WASTE.
pH
equilibrium pH after 1.0 minute
(false pH), instantaneous value after reagent addition
equilibrium lag
instantaneous pH due to CO2 liberation
control point
at control point buffer index, σ = ΔpH/Δφ = 0.673
control reagent: Ca CO3 slurry, 56.5 gms. per liter
sample: 940 c.c.
φ
MILLIEQUIVALENTS OF CONTROL REAGENT PER LITER PROCESS LIQUOR

Fig. 16. Acidity characteristics of process containing equilibrium lag due to pseudo equilibrium of chemical reactions. pH regulator controls process on basis of dotted characteristic. Process actually follows solid-line characteristic.

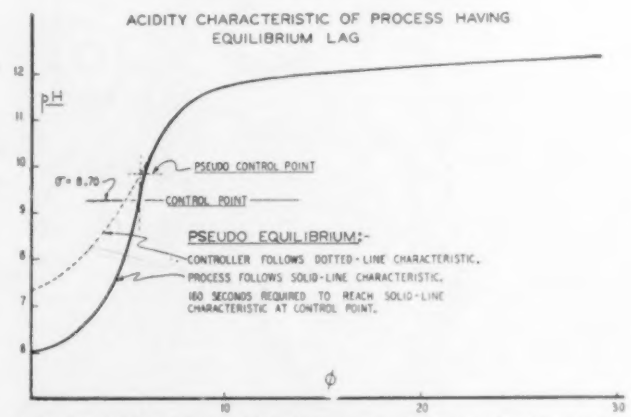


Fig. 17. Acidity characteristic of process containing equilibrium lag due to pseudo equilibrium of chemical reactions. pH regulator controls process on basis of dotted-line characteristic. Process actually follows solid-line characteristic.

in some cases that the same or better results can be achieved in a low-residence system with cascaded regulators at a cost much below that of a large tank and its agitator.

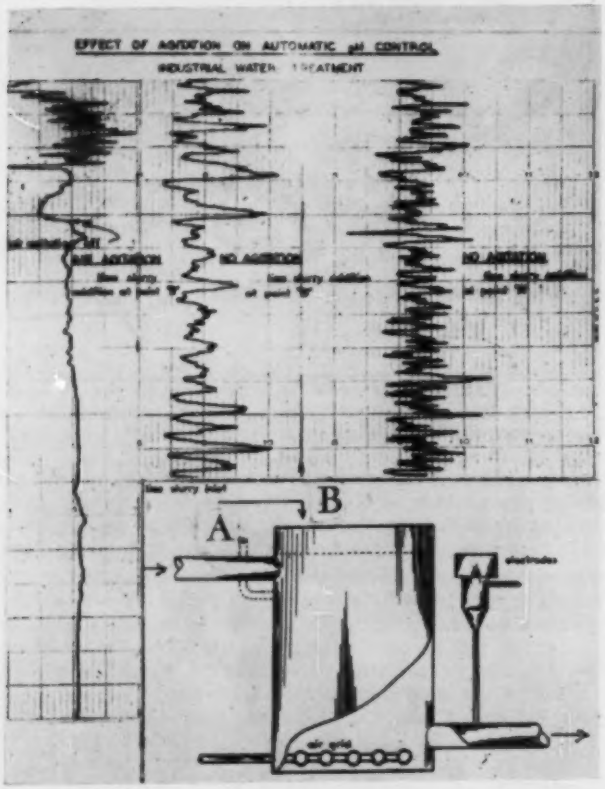


Fig. 18. Relative effect of short-circuiting in pH control residence system with and without agitation. Addition of reagent at point A results in greater short circuiting and inhomogeneity than addition at point B. Compare right-hand chart with center chart.

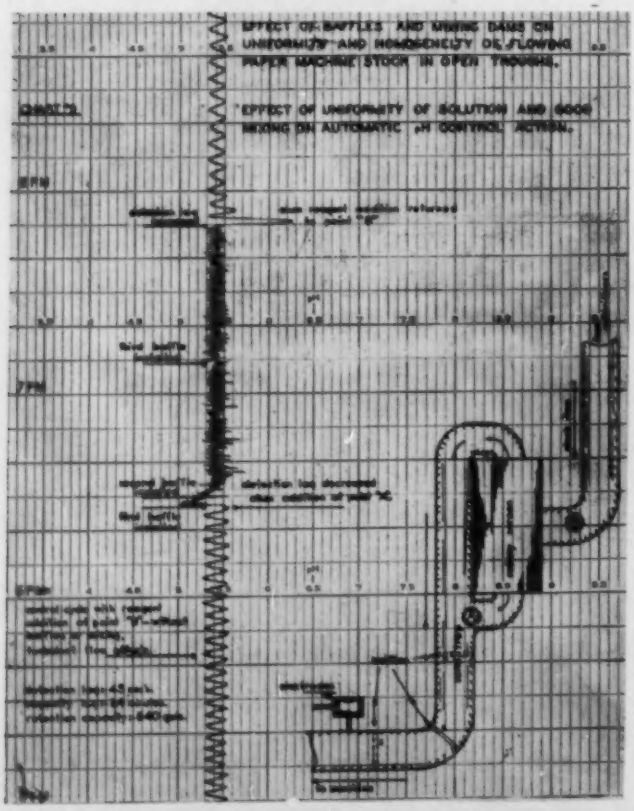

EFFECT OF BAFFLES AND MIXING DAMS ON UNIFORMITY AND HOMOGENEITY OF FLOWING PAPER MACHINE STOCK IN OPEN TROUGHS.
EFFECT OF UNIFORMITY OF SOLUTION AND GOOD MIXING ON AUTOMATIC pH CONTROL ACTION.

Fig. 19. Illustrating relationship between detection lag and equilibrium lag and their relative effect on pH control.

Quite frequently the process control engineer is required to adapt a pH regulator to an existing residence system without regard to the ratio of retention to reaction time. In such cases agitation is required and the power expenditure is higher than normally would be required if the system were designated properly for the reaction.

Fig. 18 is an illustration of equilibrium lag resulting from insufficient or poor agitation: It is of particular interest to note the difference between the right-hand chart and the center chart. Both charts are representative of no agitation but they show the relative effects of short circuiting on equilibrium when the reagent is added at the two different points illustrated. The central chart represents greater uniformity of output than the right chart. With agitation and reagent addition at the point of minimum short-circuiting, the left-hand curve is representative of the control obtained.

A second, and very important, illustration of equilibrium lag as affected by agitation is given in Fig. 19. This represents an actual chart record of pH control obtained at the sand trap of a paper machine, the plain view of which is shown. The sand trap is an open trough which conveys pulp to the paper machine, and, in this case, passes through a rotary screen.

Starting at the bottom of the control record and reading up, the lower portion represents the control obtained with reagent addition at "B" and electrodes located as shown but without baffles or agitation in the trough. Detection lag, inclusive of distance-velocity and transfer components, was 45 seconds.

At approximately 6:25 P.M. (chart time), two baffles were inserted as shown and the point of reagent addition moved to point "A" to reduce detection lag. The process was operated until 7:10 P.M. thus producing the unhomogenous record shown. At 7:10 P.M. a third baffle was installed and the process operated until 7:50 with the improved homogeneity illustrated by this portion of the chart. At 7:50 P.M. the point of reagent addition was returned to point "B" and the baffles retained with the overall improve-

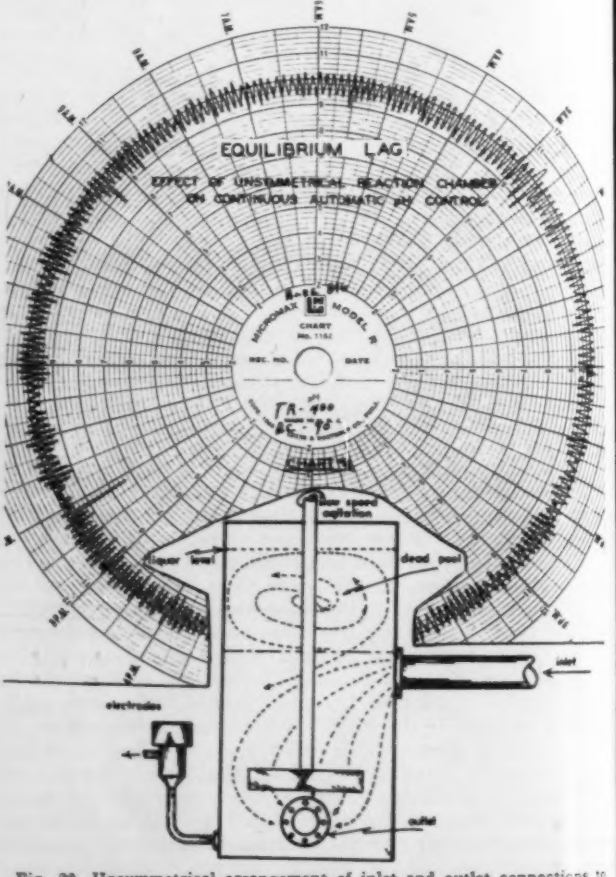


Fig. 20. Unsymmetrical arrangement of inlet and outlet connections to control tank aggravates short-circuiting and produces dead pools resulting in equilibrium lag.

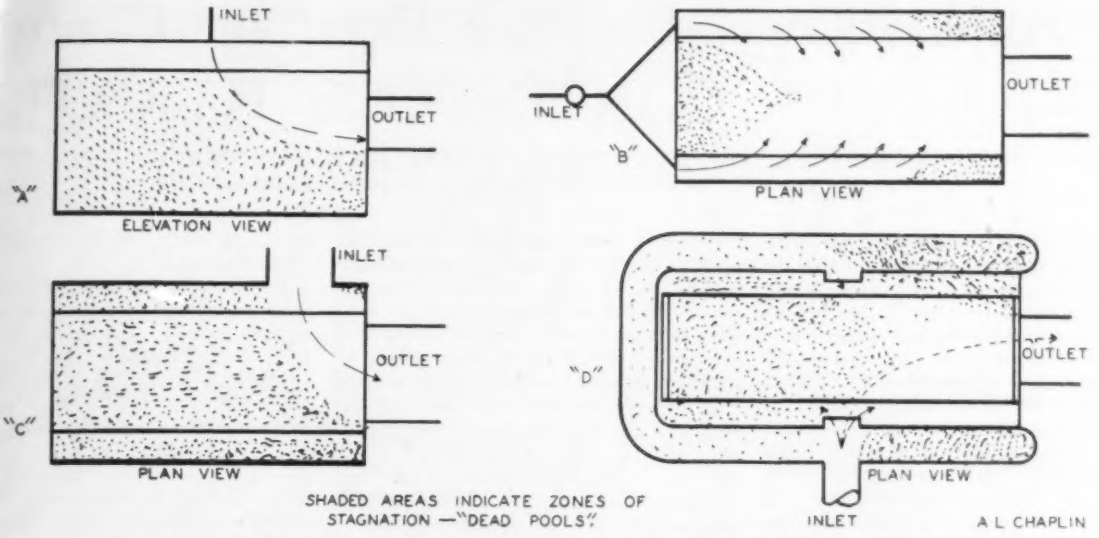


Fig. 21. Schematic illustration of rotary screens used at the paper machine. Showing the effect of short-circuiting and non-homogeneity which result in equilibrium lag.

ment in homogeneity indicated by the uppermost portion of the chart.

The important point to observe here — and it is an extremely important factor in pH control — is that while detection lag is normally regarded as a factor which must be kept small and good agitation must prevail, the over-all results of this process were improved by *increasing* the detection lag to remove *equilibrium lag*. The lowermost portion of the chart shows greater uniformity than the lower middle section while the upper middle section represents the best homogeneity attainable with the smaller detection lag. However, by increasing the detection lag sufficiently to permit reactions to reach equilibrium, the uppermost portions of the chart certainly represents an over-all improvement. The cycling record is wholly due to physical constants of the control process which are inherent limitations set by the equilibrium lag of the system.

The mere application of an agitator to a residence tank is no criterion or assurance of effective agitation. The larger the tank, the greater the power required to effectively turn over the material to avoid equilibrium lag. If the agitator is bulky and slow-speed, and if the influent material enters tangentially to the direction of rotation, the material will rotate spirally as a bulk with low turn-over efficiency. If the impeller is too small, it will not transmit enough power for effective blending.

It is generally recognized that for good pH control, especially when precipitates are formed or slow reactions prevail, the tank contents should be turned over at least twice the throughput rate and the direction of turn-over should be against or obliquely to the direction of inflow. Many articles have been written on agitation and the reader is referred to them for further study.

Another commonly-found form of equilibrium lag is illustrated in Fig. 20. Unsymmetrical arrangements of inlet and outlet piping usually aggravates short-circuiting and forms a dead pool which circulates within itself at a period of turnover different from the active portion of the residence tank, and out of phase with the regulator. The dead pool is just as effective in changing pH of the active portion of the tank as is the reagent control valve, and since the two are not in phase, the result is a wild control which cycles at a period equal to the algebraic difference of the two effects.

Piping connections to residence tanks within a pH control loop should be symmetrical and adequate turn-over provided to minimize short-circuiting and to eliminate equilibrium lag caused by dead pools.

The process control engineer is frequently called upon to regulate pH of a system wherein heavy suspensions of differing densities are processed. The tendency for these materials to segregate or settle out presents one of the most difficult problems of pH control. Starch suspensions or

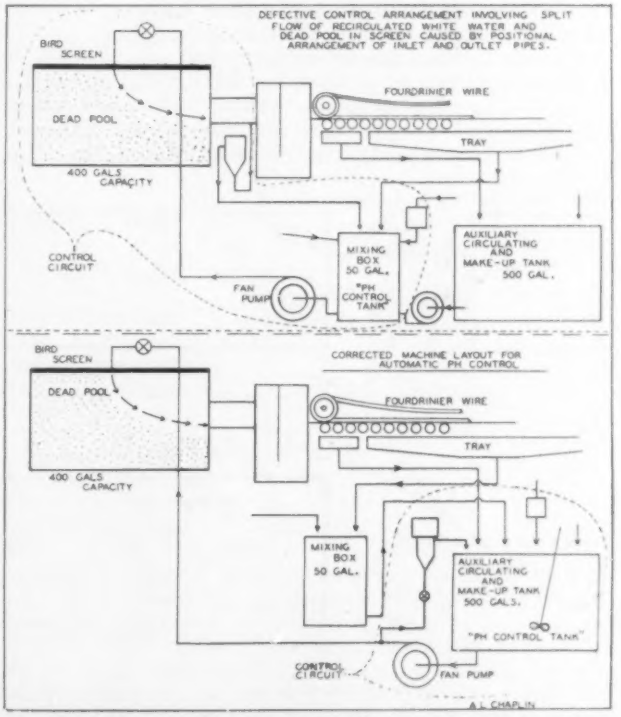


Fig. 22. Schematic illustration of Fourdrinier paper machine. Upper diagram shows defective layout incorporating equilibrium lag. Improved layout (lower diagram) eliminates undesirable aspects of upper installation.

paper pulp are good examples: these materials must be kept in motion to avoid settling and dead pools must be avoided, or otherwise, the process unit which is infected with dead pools must be eliminated entirely from the pH control loop.

Fig. 21 is a schematic illustration of rotary screens used in paper mills for classification of pulp fibres. The principle of operation of these units favors the accumulation and separation of pulp into zones of stagnation or dead pools with resultant short-circuiting of the unit. Stabilized pH control cannot be obtained with such conditions prevailing in the control loop unless the buffer index of the process is 0.1 or below; and they should be avoided entirely where possible.

Fig. 22 is representative of a pH control installation at a Fourdrinier paper machine. The top view illustrates a defective control loop incorporating the dead pool of a rotary screen. The electrodes receive a test sample immedi-

(Continued on page 608)

An Application of Feedback Electronic Control to AUTOMATIC CONTINUOUS TITRATION

By ROBERT R. AUSTIN, GEORGE K. TURNER, and L. EARL PERCY,
Research Chemists, Consolidated Engineering Corporation, Pasadena, Calif.

AUTOMATIC continuous measurement and recording of concentration is an important field of instrumentation. Titration, though one of the most common procedures for measurement of concentration, has presented many serious problems when considered as a means of continuously recording concentration. Study of these problems was undertaken during the war with the support of NDRC and later C.W.S. This work advanced the techniques of automatic titration and led to the development of an entirely new titration method capable of providing truly continuous automatic titration. Philip A. Shaffer* advanced the theory that a chemical titration cell can be made a part of the feedback loop of a negative-feedback amplifier, by utilizing the amplifier output current for the electrolytic generation of the titrating agent in the cell and using as input to the amplifier the voltage obtained from an electrode pair of the type used for determination of endpoint in potentiometric titration. One member of such an electrode pair responds to small changes in the concentration of the titrating agent. The amplifier in such a system automatically operates to equalize the rate of generation of titrating agent to the rate of addition of the reactive compound to be titrated. Since titrating agent is measured in terms of electric current, continuous recording of concentration is easily accomplished in such an instrument.

Shaffer and his associates were successful in designing an instrument embodying this principle and utilizing bromine as the titrating agent. An operating model of the instrument was produced and some data obtained for the determination of mustard-gas concentration in air. This work indicated the possibility of developing the high sensitivity required for the measurement of trace quantities of such gases as mustard in air or in other gas mixtures. Further development was therefore undertaken for C.W.S. (later the Chemical Center) by the Consolidated Engineering Corporation, where a new cell and amplifier were developed and an instrument built for practical field and laboratory work. Preliminary studies of some reactions of interest to industry have been made, with encouraging results.

*P. A. Shaffer, Jr., Anthony Briglio, Jr. and J. A. Brockman, Jr., "Instrument for Continuous Automatic Titration," *Analytical Chemistry*, Vol. 20, 1948, page 1008.

Principle of Operation

The principle utilized in the new method is shown graphically in the block diagram of the amplifier and cell, Fig. 1. The cell is shown in dotted lines as a part of the feedback network. It will be noted that the sensor electrodes of the titration cell are a part of the input network of the amplifier. The presence of bromine in the cell gives rise to a voltage between the cell "sensor electrode" and a stable reference electrode immersed in the cell electrolyte. This voltage is opposed by a reference voltage which may be pre-set to the value wanted across the sensor electrodes at the concentration of bromine desired as "endpoint" concentration for titration in the cell.

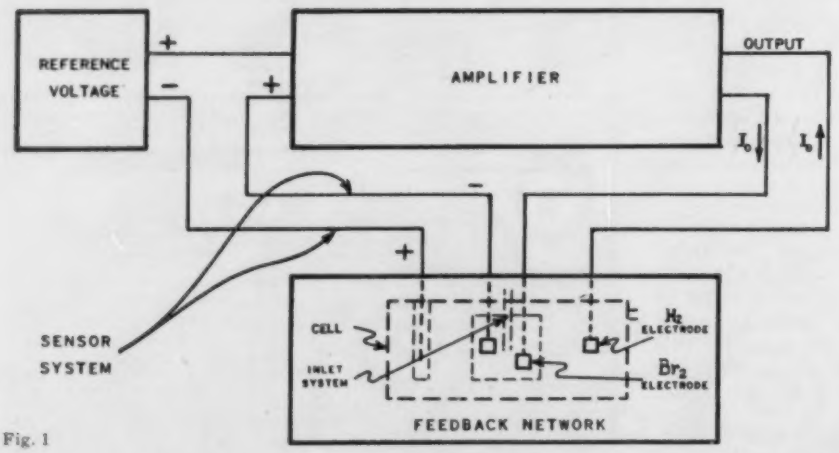


Fig. 1

Conditions in the system at the start of operation may now be considered. No bromine will be present in the cell; the reference voltage will therefore exceed the voltage from the cell electrodes, giving rise to a net voltage in the amplifier input circuit. The amplifier response to this signal will produce high output current in the feedback loop where bromine will be generated in the titration cell.

As the concentration of bromine increases, voltage will increase in the cell sensor-electrode system until equality with the reference voltage is approached. At this point the input voltage will approach zero and bromine generation will practically cease. In practice, where gas is sampled, the passage of gas through the cell carries some bromine away so that an extremely low "zero" current continues to flow in the bromine-generating circuit to maintain "endpoint" concentration.

When reactive gas is admitted to the titration cell, bromine concentration begins to fall. Since the endpoint concentration is set in the range of high electrode sensitivity, an infinitesimal decrease in bromine causes an input signal to be imposed upon the amplifier to increase generating current sufficiently to satisfy the demands of the reaction and maintain the endpoint bromine concentration.

The relation utilized in the method is given by a simple equation:

$$E_F = (E_R AB)/(1 + AB)$$

where E_F is feedback voltage;
E_R is reference voltage;
A is amplification (output current over input voltage); and
B is feedback ratio (output voltage over input current).

It is obvious that where high amplifier gain is used and the feedback ratio approaches unity, $1 + AB$ approaches AB and the feedback voltage approaches the reference voltage, which means that endpoint bromine concentration is automatically maintained constant to a high degree of accuracy.

Features

Work with the experimental model described by Shaffer showed that high sensitivity was inherent in this method. On the other hand, extensive work was required in order to develop cell and amplifier designs with which stable operation could be obtained. While the scope of this article will not permit a discussion of the problems encountered in the design of a practical instrument, it is of interest to note some important steps in the process. The titration cell has been redesigned and fabricated entirely of glass with the exception of the electrodes. This step has improved operation and eliminated trouble from traces of titrable compounds which, because of the extreme sensitivity of the instrument, would persist for long

eriods of time. New amplifier circuits ith the required sensitivity and sta- lity have been developed. The most sig- ficant feature of the amplifier design the use of two synchronous vibrators, he first to convert the input signal to he amplifier to a.c. and the second to ectify the amplifier output for use as romine-generating current. Certain pplications of the instrument require ntegration of the titrating current ver a period of operation. This has een accomplished by the development f a microcoulometer, utilizing the rinciple of capacitor charging and ischarging through a trigger circuit. oulombs are registered on a numerical ounter.

These components have been incorpo- ated in the design of the portable in- trument shown in Fig. 2, which is suit- ble for laboratory and field operation. t is operated on 115-volt a.c. or 6-volt .c. Titrating current is registered on milliammeter located on the instru- ment control panel as shown. Continu- us recording of current is accomplish- d by connecting a recording milliam- meter in the circuit by means of a hone-jack plug. Additional design fea- ures contributing to convenience of peration are:

1. Automatic protective circuits which prevent damage if the instru- ment is connected to d-c. power and set to operate on a.c. or vice versa.

2. Protective shut-off switch set to operate if the instrument is tipped be- yond a safe angle for cell operation.

3. Filters which are provided for con- nection in the gas inlet system when "zero" operation is required in the field for regulation of bromine "endpoint" concentration.

4. Gas metering orifices in the inlet to the cell and in the pump valve, per- mitting selection of any one of four con- centration ranges.

Performance

Extensive work has been done in order to evaluate the performance of this instrument for measurement of mustard-gas concentration, and some work has been done on related sulphur compounds of more general interest, such as mercaptans, organic sulphides, and disulphides.

TABLE I

Date	Run	Mustard gas net titration level, ma.	Analyses Eq. Br_2 per mol mustard
3-12	48	0.442	1.90
	49	0.56	1.89
3-23	51	0.545	1.93
	52	0.473	1.92
3-24	53	0.463	1.91
	54	0.430	1.92
3-25	55	0.455	1.94
3-26	56	0.468	1.94
			Avg. 1.91

Zero Level Stability.—The new all-glass titration cells are found to be very stable after about 24 hours of run-in operation. Such a cell will reach stable operation after a period of standing in 30 minutes to one hour. Drift of the "zero" level current is less than 1 percent of full scale for 24 hours.

Amplifier Stability. — The amplifier gain stability does not affect the accuracy of data since variation in amplifier gain only increases by an infinitesimal amount the input signal to the amplifier required for a given current output.

Reproducibility of Analytical Data. —Data reproducibility depends on a number of factors of which electrode stability and absorption efficiency for the tritrable compound in cell electrolyte are important. Extensive work was required to develop stable electrode performance. Absorption efficiency has been found to be maintained over long periods.

In Table I data are given for the measurement of mustard-gas concentration in air. It will be noted that a 14-day period is covered by these data and that the over-all agreement is within plus-or-minus 1.5 percent. For data taken the same day, the agreement was within plus-or-minus 0.5 percent.

The mustard gas supplied to the instrument in these runs was determined by the loss in weight of a special microfeeder developed for this work. Analytical procedures based upon the absorption of mustard in various solutions, followed by titration, were tested but satisfactory agreement of data could not be obtained with any of them.

Sensitivity.—The limit of sensitivity of the instrument here described, operating at an air-flow rate of 1 liter per minute, is 0.1 p.p.m. beta-beta prime dichlorodiethyl sulphide in air.

Range of Compounds Titrated. — Compounds thus far studied have been largely organic compounds of sulphur and other compounds which might be expected to interfere with sulphur measurement. The following compounds have been successfully titrated: H_2S, SO_2 and mercaptans.

The following compounds have been found not susceptible to titration: CO, CS_2, aldehydes, ketones, olefins, diolefins, and acetylene.

The various sulphur compounds have been found to differ somewhat in solubility in the titration-cell electrolyte, so that calibration of the instrument is required for each compound of interest. The reliability of such calibration data for operation over extended periods is of primary importance. Many data bearing on this question have been obtained, some of which are given in Table II, for operation on butyl mercaptan.

TABLE II
Butyl mercaptan analyses

Date	Run	Net titration level, ma.	Eq. Br_2 per mol RSH
1-10	4	0.42	2.37
	5	0.53	2.28
	7	0.64	2.27
1-13	4	0.36	2.36
	5	0.23	2.43
2-8	1	0.38	2.37
			Avg. 2.35

Experimental field work relating to the measurement of the concentration of sulphur compounds is in progress. Work is also being directed toward the design of instruments of this type for future commercial manufacture.

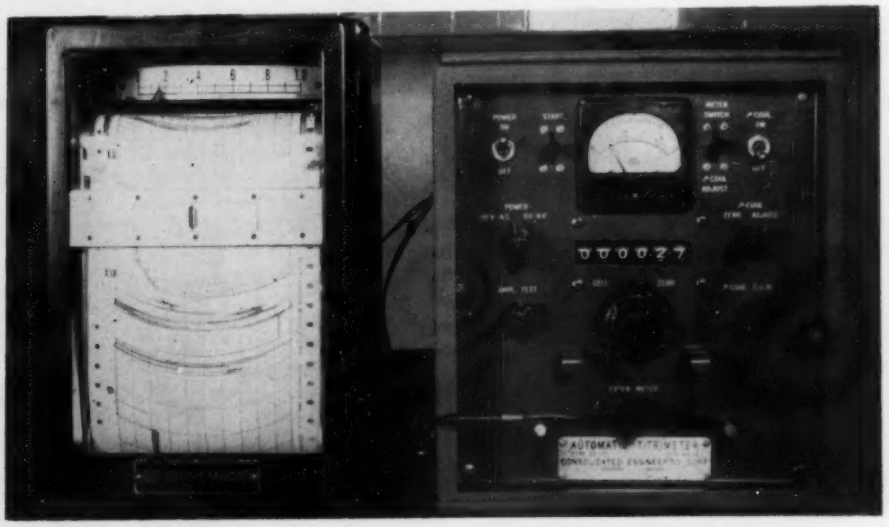


Fig. 2

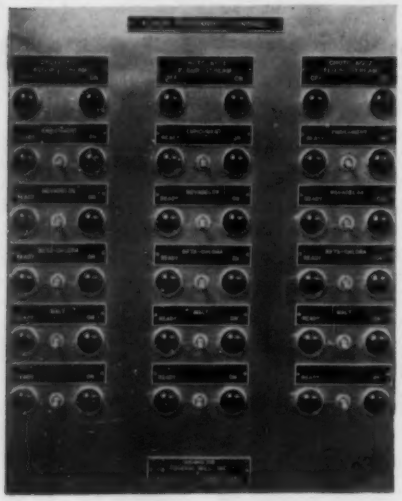
The Month's NEW INSTRUMENTS

In this department we report each month new devices for measurement, inspection, testing, metering and automatic control — in the form of concise technical descriptions.

FOR FURTHER INFORMATION USE THE POSTAGE-FREE ORDER CARD ON PAGE 631

Flow-ratio System for Liquids and Granular Materials

New "Signa-Flow System" electronically operated flow detector and control system is designed to automatically synchronize the flow of two or more materials and to shut off feed lines in

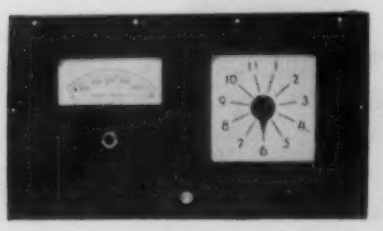


any given mix when a flow stoppage occurs in any line from clogging or other causes. When stoppage is cleared, "Signa-Flow" automatically resumes operations. System can detect flow or non-flow of any ingredient, even when flow is as slight as a few ounces per minute. A flow stoppage is indicated on a light panel. Horns and vari-colored lights warn of blending irregularities in complex mixtures. Maker's engineering staff designs complete milling operation layouts using "Signa-Flow" control devices.—*Buffalo Electronics Corp., 429 Southwood Drive, Kenmore 17, N.Y.*

Mention No. 701 when filling out card.

Diesel Exhaust Pyrometer

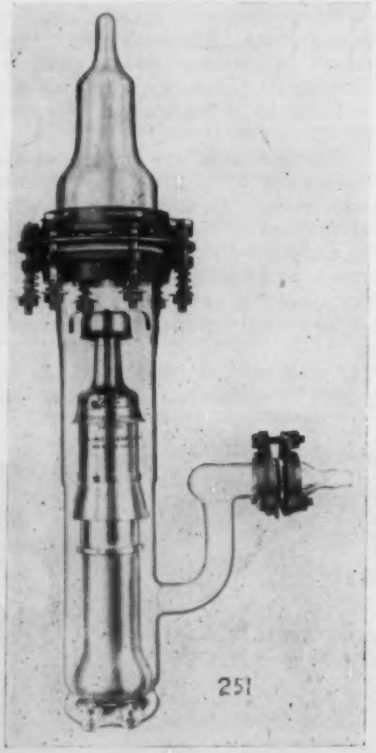
New "1160 Pyrometer" is a continuously-operated monitoring instrument for automatically measuring cylinder exhaust temperatures of diesel engines. Clock-like dial indicates switch positions, can be easily read from 20 feet. Pyrometer indicator is maker's "R-type" movement with a new, more legible scale. Switch has a motor-driven rotary-type arm (1 rpm.) actuating leaf type contact assemblies. Overlaps in rotary switch keep pointer from returning to zero between positions: any large deviation from a general average is immediately shown on pyrometer scale. A push button on front panel enables operator to stop rotating switch on any selected position for longer readings. Instrument can be equipped with an Excess Temperature Cut-out which activates alarm systems or stops engine if any cylinder should reach excessive exhaust temperatures.—*Illinois Testing Labs., Inc., 420 N. LaSalle St., Chicago 10, Ill.*



Mention No. 702 when filling out card.

Oil-diffusion Vacuum Pump

New "HV-1" vacuum pump is an oil-diffusion type originally designed by maker's engineers for their own use in manufacture of vacuum tubes. Features

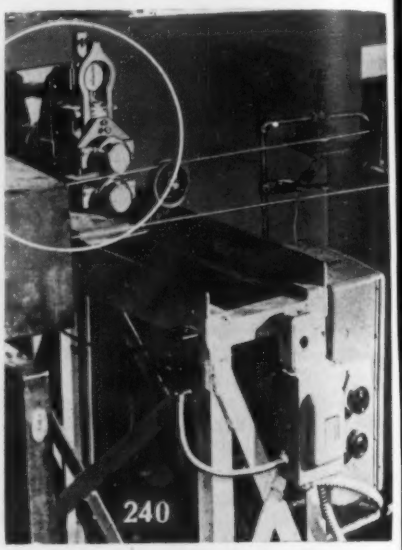


include: speeds up to 67 liters per second, attainable vacuum of 0.0004 micron mercury, clear glass pump barrel, no liquid cooling, no charcoal trap, no mechanical wear, and simplicity of mounting and maintenance. — *Eitel-McCullough, San Bruno, Calif.*

Mention No. 703 when filling out card.

Wire-coating Gage and Automatic Controller

New "Model 493 B-59 Continuous Measuring Gage" measures thickness of plastic coating deposited on copper electrical wire; and "Electricator" transmits electrical impulses when dimens-

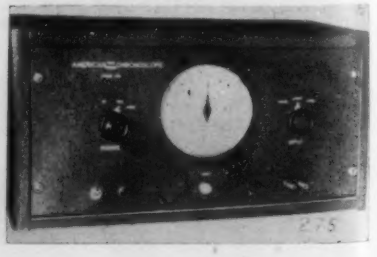


ions are out-of-tolerance, thereby controlling machine so that a uniform coating thickness is maintained. If desired, a continuous thickness recorder can be installed. Parallel rollers contact coated wire. Rollers maintain their parallelism regardless of thickness. Pressure of rollers can be varied to suit hardness of coating material. Gage is easy to install. Other types are available for glass tubing, metal rods, strip material and other continuously-produced material. — *Federal Products Corp., 1144 Eddy St., Providence, R. I.*

Mention No. 704 when filling out card.

High-speed Chronoscope

New "Model 100" chronoscope measures time intervals ranging from 10 microseconds to 1 second with an accuracy of 1 percent. Instrument is said to be applicable for bother mechanical and electrical measurements ranging



from relays to photographic shutters and from radar equipment to thyratron tubes. It operates on capacitor-discharge principle. A self-balancing potentiometer measures percentage loss, and time interval is read directly from 5-in. scale. Mechanical operations may be timed either by causing them to short circuit instrument for duration of action to be timed, or by opening circuit. Electrical phenomena can be measured by producing any voltage from 6 to 120 volts at instrument input. Chronoscope has four overlapping ranges.—*American Chronoscope Corp., 318 W. First St., Mount Vernon, N. Y.*

Mention No. 705 when filling out card.

Servomotor

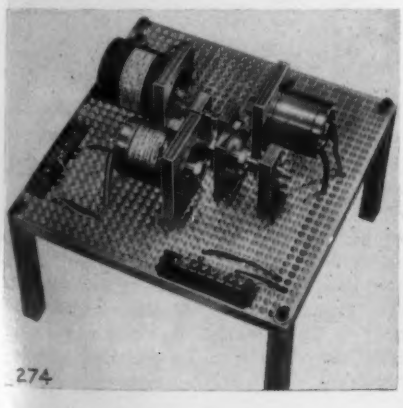
New servomotor employs plate-to-plate type of operation and is therefore said to conserve considerable space

and weight in industrial uses. Motor stall torque ranges from 0.25 in.-oz. to 4.25 in.-oz. Design of new servomoter eliminates output transformer in servo-amplifier through direct winding.—*Transicoil Corp., 114 West Worth St., New York 13, N. Y.*

Mention No. 706 when filling out card.

Servomechanism "Breadboards" for Experimental Purposes

New "Mechanical Development Apparatus" consists of an 8x8-inch aluminum base plate (illustrated) and user's choice of blocks with bearings, blocks with T-slots, angle mountings, shafts, shaft stops, precision-cut stainless-steel gears, mounting screws, etc. Also available are various elements such as amplifiers, rotary-type voltage dividers, power supplies, synchro devices, servo-



motors, etc., whereby complete servomechanisms can be easily assembled and quickly connected to inputs and loads in a manner reproducing intended service conditions. Thus, resulting assemblies are not analogs but are practically-operable servomechanisms set up for performance tests of various types, whereby response to actual random inputs of their intended service can be predicted with certainty—and whereby alterations in system's components and electrical and mechanical characteristics can be made between one series of tests and the next. (Hence "Development" in name of new apparatus.) Variety of performance-test techniques is unlimited: actual limits in each case are set by ranges, responses, etc., of indicating and recording instruments at disposal of user. Average laboratory has adequate instrumentation; if not, undersigned company can make recommendations.—*Control Systems Co., GPO Box 334, New York 1, N. Y.*

Mention No. 707 when filling out card.

Magnetometer

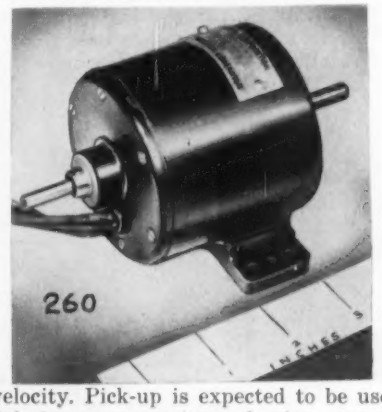
New "Series MS-1001 Macelwane-Sprengnether Magnetometer" and accessories are especially designed for

preliminary magnetic surveys and for student training. Magnetometer embodies all best principles of design incorporated in elaborate Schmidt-Type field balances. Vertical Component Magnetometer is supplied with tripod, a compass, one auxiliary magnet, a graduated compensating bar (which may also be used for determining magnetometer scale constant), and a mahogany finish carrying case. Special feature is design of bearings on needle system. Instead of a quartz knife edge, needle system is pivoted on two hardened points which rest on polished sapphire bearings. If instrument is accidentally jarred, or picked up while system is unclamped, no serious damage is caused to pivots. If pivots should become injured through careless handling, they may easily be replaced, or sharpened (cost of replacement bearings very small). Sapphire bearings on which they rest will probably never be injured by careless usage. Sensitivity and balance adjustments can easily be made. Entire magnetic system (needle, bearings, damping vanes and lifter) may be removed from case as a unit. When removed, needles are held in locked position under spring tension. Transparent scale is set into side of case. No mirrors or separate reflectors are necessary to illuminate optical system. Although sensitivity can be adjusted to a high degree, most practical range for beginners, etc., is about 50-75 gammas per scale division. It is possible to estimate to tenths of a division by fine index line. Weight of complete instrument and carrying case, 6.75 lbs., tripod, 6.5 lbs. —*Sprengnether Instrument Co., 4567 Swan Ave., St. Louis 10, Mo.*

Mention No. 708 when filling out card.

Acceleration Pick-up

New acceleration pick-up is a d-c. generator with voltage proportional to acceleration of rotor rather than to its

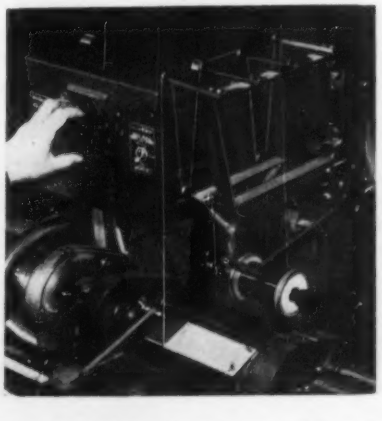


velocity. Pick-up is expected to be useful in servo systems having severe damping problems and where necessary to measure or limit acceleration. Current of 0.12 amp. in 350-ohm field delivers 0.1 volt for acceleration of 1,400 radians per second squared. Maximum speed, 5,000 rpm. Rotor inertia, 0.25 oz.-in. squared.—*Arma Corp., 254 36th St., Brooklyn 32, N. Y.*

Mention No. 709 when filling out card.

Continuously-variable Motor-speed Control Unit

New "Type 1700-A Variac Speed Control" is for operating a 0.3 hp. d-c. shunt motor from an a-c. line. Constant field voltage is supplied by a dry-disk rectifier; armature voltage can be var-



ied by a Variac autotransformer feeding an electronic rectifier. Smooth control is obtained from motor-rated speed down to practically zero. Regulation in rpm. is constant at all speed settings and is adequate for most applications, although not as low as that of the more complicated compensated thyratron controls. A-c. ripple in armature circuit is far less than that of a thyratron control, and consequently motor losses are lower, so that motor operates at its full d-c. rating. Overload capacity for starting is several times full-load armature current. Full protection is provided by a circuit breaker. Dynamic braking is provided in "STOP" position. Field voltage can be adjusted in steps to change maximum speed. Both 115-volt and 230-volt models are available. —*General Radio Co., 275 Massachusetts Ave., Cambridge 39, Mass.*

Mention No. 710 when filling out card.

Inspection Magnifiers

New clamp-on inspection magnifiers are available in five lens sizes: 2.5, 3, 3.5, 4 and 4.5 in.; have true optically-

ground and polished lenses in polished aluminum rims; chrome-plated two-ball-type swivel; and clamp for attaching to any reflector, leaving both hands free for inspection, assembly or adjustment work.—*Testrite Instrument Co., 59 East 11th St., New York 3, N. Y.*

Mention No. 711 when filling out card.

Capacitance Comparator

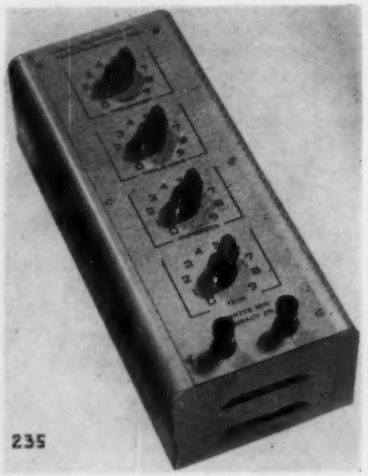
New "Model PC-4" automatic capacitance comparator is for use by unskilled operators in grading, sorting

or checking all types of capacitors at a rate up to 5,000 per day. Instrument has an accuracy of 0.2 percent, is used on any 110-volt a-c. line and is a self-contained unit. Direct readings are made in percent on 4 in. indicator over range of 10 micromicrofarads to 1,000 microfarads.—*Clippard Instrument Lab., Inc., 1125 Bank St., Cincinnati, Ohio.*

Mention No. 712 when filling out card.

Decade Power Resistance Box

New "Model 10" decade power resistance box can be employed both in service and laboratory work for determin-

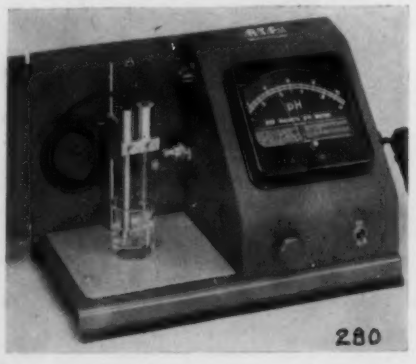


ing proper resistance values by substituting or for replacing 0.5 percent boxes used as standards, which are damaged by appreciable loads. New unit is four-decade type featuring power handling capacity, 2 percent accuracy and wide range. Coil disippation minimum is 10 watts, maximum is 30 watts, and total available resistance is 99,990 ohms. Recommended for all audio and lower radio frequencies.—*Marma Electronics Co., 1632 North Halsted St., Chicago 14, Ill.*

Mention No. 713 when filling out card.

pH Meter for Graphic Industries

New pH meter has been developed by American Type Founders in collabora-

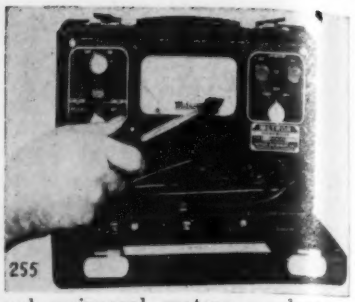


tion with undersigned company for measuring degree of acidity or alkalinity of offset press water fountain solutions, and solutions used for plate coating or etching.—*Macbeth Corp., 227 West 17th St., New York 11, N. Y.*

Mention No. 714 when filling out card.

Tachometer

New "Model 48K" extends maker's line of 0.25 percent accuracy tachometers to include ranges for most motors and generators. Selector switch permits measurement of speeds in 10 separate ranges between 360 and 4,000 rpm. Instrument can be used with adapter for measuring speeds of high-



speed universal motors or low-speed geared motors. Instrument is permanently lubricated, has no short-life components, and operates at low torque.—*Metron Instrument Co., 432 Lincoln St., Denver 9, Colo.*

Mention No. 715 when filling out card.

Inspection Magnifier

New 14-power inspection magnifier contains three lens elements of different characteristics cemented together to

give a true flat field of 0.5 inch free from color fringes and distortion as common in ordinary magnifiers. Folds into chrome-plated case with loop for chain and space for engraving name (which is included in price).—*Buhl Optical Co., 1009 Beech Ave., Pittsburgh 12, Pa.*

Mention No. 716 when filling out card.

Rapid-commutating Rotary Switch

New "High Speed Subminiature Mechanical Sampling Device" (switch) has two poles, each of which contains sixty

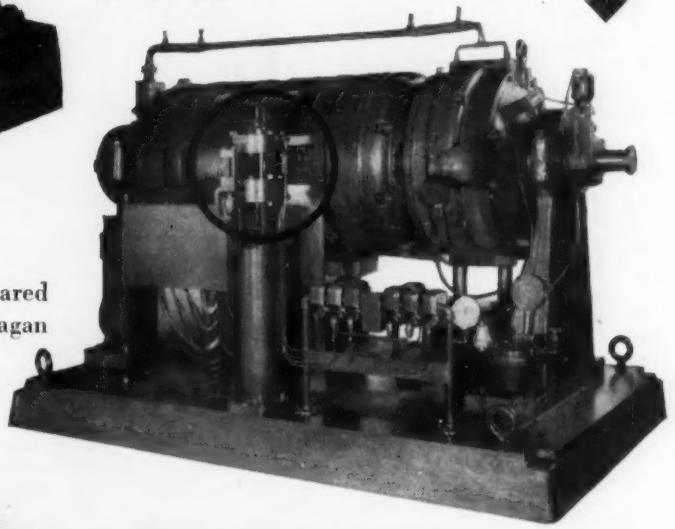
contacts. Poles may be synchronized in any phase desired. Device is totally encased. Switch rotor may be manually turned by a screw driver adjustment, accessible through a hole plug. New switch is driven by a 12- or 28-volt d-c. motor and has a power consumption of only a few watts. Sampling rate is nominally 300 rpm. In addition to telemetering applications, new switch may

Specify HAGAN THRUSTORQ

when you buy dynamometers from these leading manufacturers

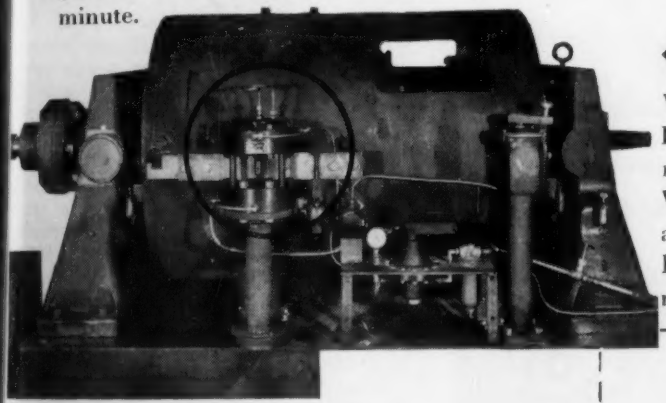
DYNAMATIC

Dynamatic Corporation, Kenosha, Wisconsin, builds dynamometers to fit virtually every testing requirement — and Hagan THRUSTORQ is featured equipment for the measurement of torque. Shown here is a Dynamatic Universal dynamometer equipped with a double Hagan THRUSTORQ.



GENERAL ELECTRIC

The General Electric Company is now prepared to supply dynamometers which employ Hagan THRUSTORQ as the torque-measuring instrument. The THRUSTORQ-equipped dynamometer shown here is a water-cooled induction type rated 250 horsepower, 2,000/6,000 revolutions per minute.



WESTINGHOUSE

Westinghouse Electric Corporation will also supply Hagan THRUSTORQ as original equipment on dynamometers manufactured by them. Shown here is a Westinghouse cradle dynamometer and THRUSTORQ assembly ready for shipping. Dynamometer is of the DC type, 100 horsepower, 1,050/4,000 revolutions per minute.

For full information on Hagan THRUSTORQ, *fill in the coupon below or write, describing the application in which you are interested, to Hagan Corporation, Hagan Building, Pittsburgh 30, Pennsylvania.*

Hagan Corporation, Hagan Building
Pittsburgh 30, Pa.

Please send me information on Hagan THRUSTORQ particularly in relation to:

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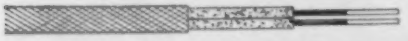
There are two good reasons why we stress Gordon Quality and Gordon Service. (1) The precision quality of Gordon Thermocouple Extension Lead Wire is based upon 32 years of experience in careful selection and inspection to meet rigid insulation requirements. (2) Gordon's Chicago and Cleveland plants carry complete stocks of Thermocouple Extension Lead Wire for practically every application. (See illustrations below.) This means that your order gets immediate delivery of a QUALITY product—one that meets Bureau of Standards Specifications. ORDER NOW! No waiting or delay. Prices available upon request.

CHROMEL-ALUMEL, Cat. No. 1231(3-A), 14 ga., STRANDED-DUPLEX, each wire felted asbestos, Asbestos-yarn braid overall.

FOR PLATINUM THERMOCOUPLES, Cat. No. 1225, 16 ga., STRANDED-DUPLEX, each wire felted asbestos, Asbestos-yarn braid overall.



CHROMEL-ALUMEL, Cat. No. 1234, 14 ga., SOLID-DUPLEX, each wire enamel, felted asbestos, Asbestos-yarn braid overall.

IRON-CONSTANTAN, Cat. No. 1236-C, 14 ga., STRANDED-DUPLEX, each wire felted asbestos, Asbestos-yarn braid overall.

COPPER-CONSTANTAN, Cat. No. 1235-A, 14 ga., SOLID-DUPLEX, each wire cotton, rubber, weatherproof braid, lead sheath overall.

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be used for display of characteristic curves and multichannel voltage comparison. Electrical operations may be synchronized with mechanical motion by appropriate attachment of switch rotor. —*The Applied Science Corp., P.O. Box 44, Princeton, N. J.*

Mention No. 717 when filling out card.

Multi-flow Rotameter

New multi-tube rotameter can be built with two or more rotameter tubes in it for use on related flows. Standard "Full-View" rotameter end fittings are

fastened to a metal back plate with dowel pins and cap screws. Front of unit is shielded with a plastic window. Each tube with its fittings may be removed without disturbing any other parts. Advantages of unit are said to be compactness, close correlation of related flows, and economy.—*Brooks Rotameter Co., Box No. B-5449, Lansdale, Pa.*

Mention No. 718 when filling out card.

Pocket Chamber Electrometer

New "Model 4SN3A1 Pocket Chamber Electrometer," for determining amount of radiation to which pocket pencil type ionization chambers have been exposed, employs a true quartz-

fiber electrometer as its sensitive element; is designed to read pocket pencil type chambers carried by personnel working in areas where radioactivity exists. Radiation values are indicated directly on a conventional 3.5-inch instrument calibrated in milliroentgens. Unit operates on two separate ranges, 0-50 and 0-250 milliroentgens, each with a separate scale. A photoelectric system using a servo principle makes new device a self-balancing electrostatic potentiometer, operating without overshoot and with performance largely independent of electrometer characteristics. A complete new electrometer element can be easily installed without recalibrating scales. Unit weighs about 20 lbs., operates on standard 117-volt a.c. with an input of 50 watts. —*Specialty Div., General Electric Co., Electronics Park, Syracuse, N. Y.*

Mention No. 719 when filling out card.

Radiation Counter

New "Nucleometer" is scaler type instrument which counts radiated particles by operating in proportional region rather than in Geiger region. To count alpha particles, instrument is set at

3100 volts; and to count beta, gamma and any alpha particles present, high voltage is adjusted to 4200 volts. Instrument incorporates Higginbotham scale of 512 with counter tube, high-voltage supply, amplifier, pulse equalizer and scaling unit. Operation at proportional region is said to provide low resolution loss, exceedingly low and flat plateau, short flashing time and minimal deposit of objectionable materials on inside of counter tube.—*Radiation Counter Labs., Inc., 1844 West 21st St., Chicago 8, Ill.*

Mention No. 720 when filling out card.

Non-reset Magnetic Counter

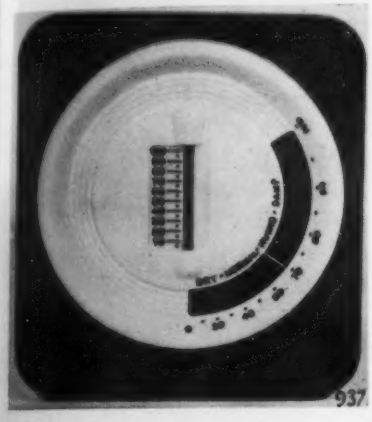
New "Series 1268 Non-reset Magnetic Counter" is designed to meet limited specifications of certain types of installations which do not require an ex-

tremely high number of accumulated counts—or high speeds. Fifty counts per minute is maximum recommended. New counter can be readily built into equipment or machines as an integral part. Standard coil 110-volt a.c.; plus-or-minus 10 percent permissible voltage variation; 8-watt maximum power consumption. No lubrication required.—*Veeder-Root Inc., Hartford 2, Conn.*

Mention No. 721 when filling out card.

Humidity-temperature Indicator

New "Humidial" is said to be much more accurate than previously available low-cost relative humidity and temperature indicators. It employs bi-plastic pointer made of laminated plastic ma-

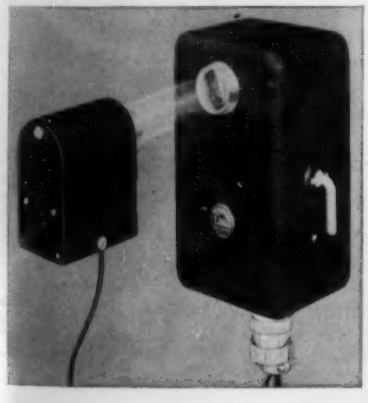


terials which change length alike with temperature changes, but only one plastic part is affected by moisture. Accuracy of 2 to 3 percent of scale is claimed when instrument is checked every several months with sling psychrometer. Instrument is said to respond quickly and is free of error due to temperature changes. "Drift" is said to be very slow and pointer can be readily reset from back of case.—*Humidial Co., 1556 Connecticut Ave., Washington 6, D. C.*

Mention No. 722 when filling out card.

Delayed-action Photoelectric Control

New "Type 20DA4" delayed-action photoelectric control is for use in packaging operations where cartons or other opaque objects move along conveyor. Instrument responds when a jam occurs and stops machinery to prevent further pile-up. Photocell and light



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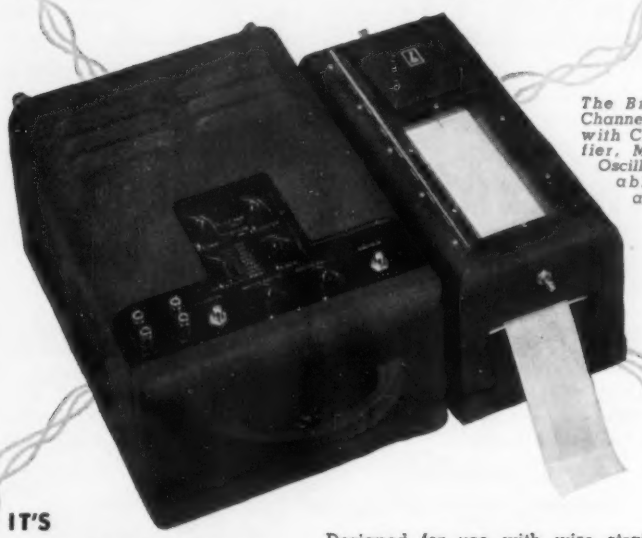

The Brush Single-Channel Oscillograph with Carrier Amplifier, Model BL-310. Oscillographs available in Double and Six-Channel units also.

IT'S INSTANTANEOUS! PERMANENT! ACCURATE! *with the*

"Strain Analyzer"

Designed for use with wire strain gages or other resistance sensitive elements. Two "Strain Analyzer" models are available, which, with suitable pickups, give immediate records of strains, pressures, temperatures, torques, vibrations or accelerations. Either static or dynamic phenomena up to 100 c.p.s. may be recorded.

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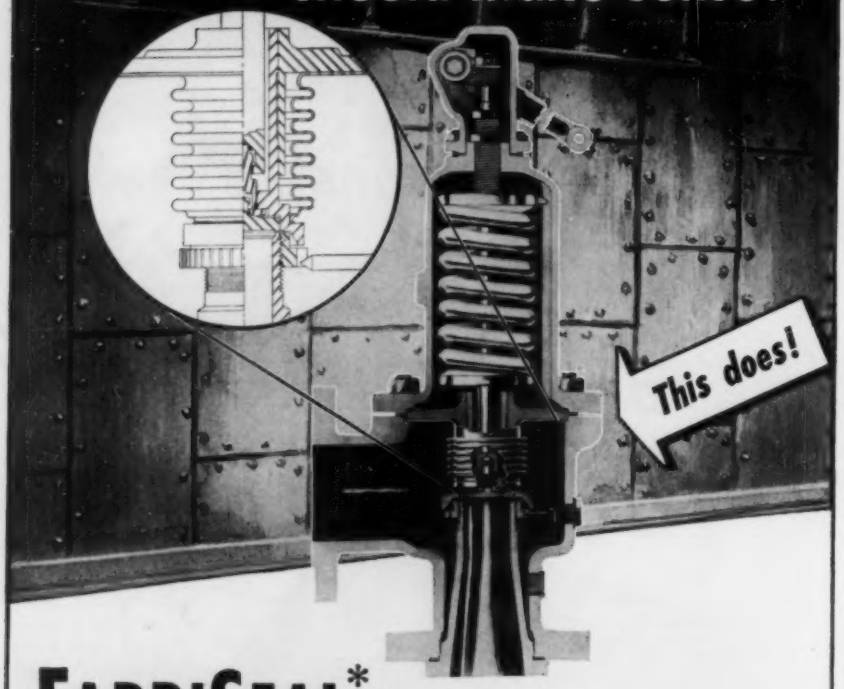

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The next time you need safety valves, don't worry about corrosion. Just remember the FARRISEAL "iron curtain" — the protective Stainless Steel Bellows. Just remember what this original FARRIS development does . . .

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- FLEXIBLY JOINS THE DISC TO THE MAIN BODY GASKET. The valve guide **can't** be fouled under any conditions.
- FULLY PROTECTS ALL WORKING PARTS FROM CORROSION.
- ALWAYS SAFE — bound to open at set pressure.

No other safety valve has these FARRIS features. Only FARRIS has designed a stock line of safety and relief valves especially for service where corrosive conditions may make ordinary valves useless.

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SAFETY and RELIEF VALVES

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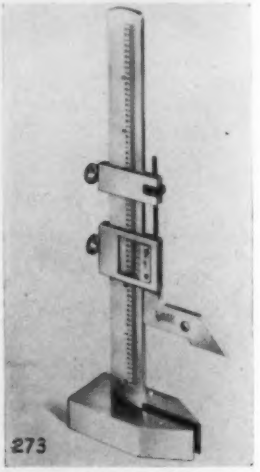
units are placed so that light beam is intercepted as packages move along normally but relay is operated to stop operation should packages interrupt beam for an abnormally long period, adjustable from 0.05 to 5 seconds. D-p.d-t. relay operates within 0.05 second; operating range is 10 ft.; photocell responds to 10-50 foot-candle illumination, and unit is available for operation with 115 or 230 volts, 50 to 60 cycle a.c.—*Photoswitch, Inc., 77 Broadway, Cambridge 42, Mass.*

Mention No. 723 when filling out card.

Vernier Height Gage

New vernier height gage provides direct readings up to 6 in. owing to slotted design of base, thus obviating need for

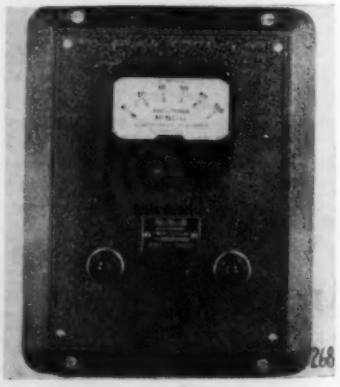


computations and possible errors. Adjustable vernier scale allows zero setting to be maintained. A scriber point is attached on jaw which also has a hole to accommodate indicators.—*Vard, Inc., 2981 E. Colorado St. Pasadena 8, Calif.*

Mention No. 724 when filling out card.

Smoke Indicator

New "Model SR146-C" smoke indicator is said to be unique in construction, enabling user merely to disconnect a cable and return unit to factory if or



when repairs and servicing are required. All components except phototube and amplifier tube are mounted on panel and a cable connector attaches terminal strip in box to chassis.—*McNeill Engineering Co., 4057 West Van Buren St., Chicago 24, Ill.*

Mention No. 725 when filling out card.

Combustible Gas Detector

New combustion gas detector and safety controller, recently approved by Underwriters Labs., provides means for continuous analysis of plant atmospheres to detect dangerous concentration of explosive or flammable mix-

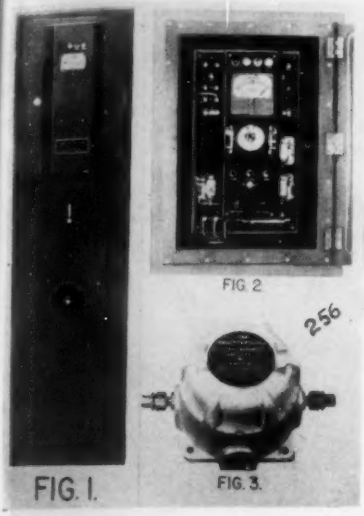


Fig. 1. Industrial type combustible gas detector, front view. Fig. 2. Cabinet interior showing control chassis. Fig. 3. Gas sampling analyzer head.

tures; actuates audible alarms and visible signals if such hazardous condition should exist. Control panel, rotary vanes and suction pump are housed in central unit from which "remote heads" are connected to any part of plant. Analyses are conducted in remote heads continuously, signaled to control unit and indicated. Instrument can be adjusted to give warning signal at any percentage of hazardous mixture from 20 to 100 percent.—*Lor-Ann Instrument Co., Inc., 58 Montgomery St., Jersey City, N. J.*

Mention No. 726 when filling out card.

Volt-Ohm-Milliammeter

New "Model 666R" pocket-size volt-ohm-milliammeter has resistance ranges from 0-3000 ohms (0.5 ohm low reading) to 3 megohms, self-contained; ten a.c.-d.c. volt ranges to 5000; three direct current ranges. Enclosed selector

switch of molded construction keeps dirt out, retains contact alignment permanently. Unit construction, whereby all resistors, shunts, rectifier, and batteries

TYPE B HIGH PRECISION POTENTIOMETER

This general purpose potentiometer, incorporating a number of notable refinements in potentiometer design, is widely used for precise temperature measurements including thermocouple standardization, for meter calibration, for checking portable potentiometers and for other critical measurements of DC potentials requiring exceptionally high accuracy. Distinctive features include:

1. Three ranges: 0 to 1.6 volts, 0 to 160 millivolts and 0 to 16 millivolts.
2. Three reading dials—effective scale length of approximately 175 feet for each range. Readings easily estimated to within one part in 100,000 of full-scale ranges.
3. Subpanel switch and slidewire construction for protection of contacts from dust and corrosive fumes.
4. Special provisions to minimize parasitic thermal emf's—including automatic compensation of slidewire thermals and gold contacts in galvanometer key.
5. Exceptional convenience in reading and adjustment.
6. Solid and substantial construction for many years of trouble-free service.

PORTABLE PRECISION POTENTIOMETER
A two-dial instrument with built-in standard cell, galvanometer and battery, available in a variety of ranges for laboratory, plant and field applications. Described in Bulletins 270 and 270A.

Thoroughly proven by practical application in exacting research investigations for nearly fifteen years. Described in Bulletin 270.

Rubicon galvanometers suitable for use with the Type B Potentiometer are described in Bulletin 320.

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Galvanometers • Resistance Standards • Wheatstone, Kelvin and Mueller bridges • Evelyn Photoelectric Colorimeter for precise chemical analysis • Automatic Recording Photometric Analyzers for NO and H_2S • Magnetic Permeameters • Shorted-turn Coil Testers • Other equipment involving precise measurement of electrical quantities.

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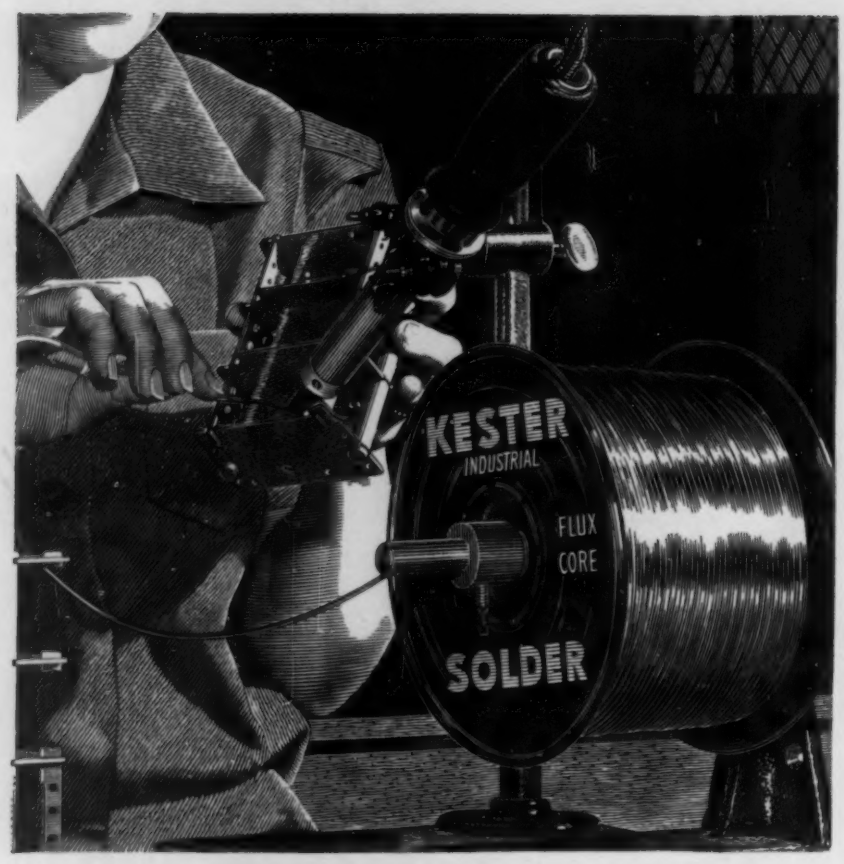

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are housed in a molded base integral with switch, eliminates chance for shorts. Direct connections. No cabling. All precision film or wire-wound resistors are mounted in their own compartment. Rectifier and batteries may be replaced easily. Handy pocket-size (less than 6 inches high).—*The Triplett Electrical Instrument Co., Bluffton, Ohio.* Mention No. 727 when filling out card.

Photoelectric Counter

New photoelectric counter is principally for use in tin plate mills for high-speed counting of sheets as they pass over spit conveyor belt. Instrument op-

erates a deflector which automatically starts new stack. Exact count is indicated by neon-glow lamps and a warning signal is sounded just before desired number is reached. Unit will count up to 60,000 per minute and is adjustable by means of selector on control unit. Counter has applications also in measuring and shearing metals, and in packaging operations.—*Potter Instrument Co., Inc., 126-56 Roosevelt Ave., Flushing, N. Y.*

Mention No. 728 when filling out card.

H-f. Voltmeter for TV, FM and Radar

New "MV-18A" vacuum-tube voltmeter measures r-f. voltages down to a single millivolt at frequencies between 1 and 200 Mc. Within this frequency range it is flat within 10 percent; for

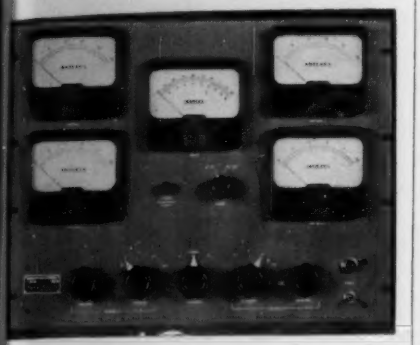
higher frequencies larger response-corrections have to be made. Instrument can be used for frequencies as high as 2,500 Mc., 10 mv. then being lowest voltage which can be read. It uses germanium "pseudo-thermocouples" as

detector and sensitive high-impedance carrier-type d-c. amplifier which converts minute voltages, developed by thermoelectric effect within germanium crystal, into readings. For high-voltage measurements (up to 1,000 volts) regular crystal diode rectification is used. Three different germanium probes are available for this purpose, having various capacitive input dividers to "trade surplus sensitivity for minimum circuit loading."—*Millivac Instruments, P. O. Box 3027, New Haven, Conn.*

Mention No. 729 when filling out card.

Antenna-system Phase Meter

New "Model 108-C" phase meter provides a simple, easily-operated means for measuring phase relations in direc-

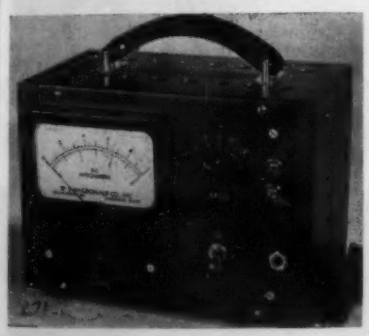


tional antenna systems; also for remote monitoring of amplitudes of currents in elements of array. Phase indicator (at center) has scale marked in two-degree intervals; half-degree increments can be readily resolved. Normally supplied for operation in standard broadcast band; other frequency ranges on special order.—*Clarke Instrument Corp., 910 King St., Silver Spring, Md.*

Mention No. 730 when filling out card.

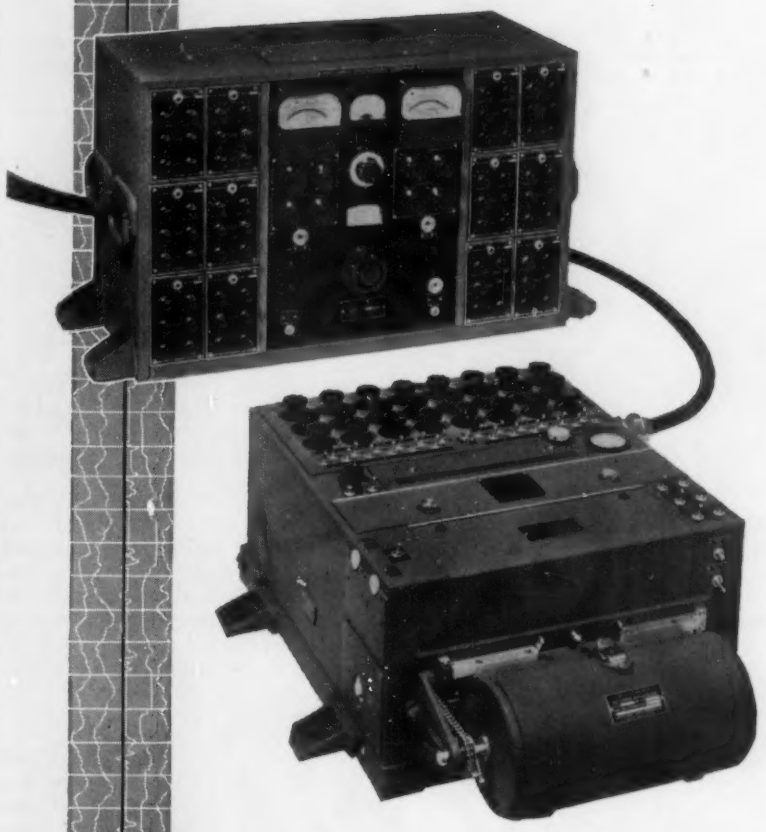
D-c. Microammeter

New "Model 100" d-c. microammeter and magnetic amplifier fills weak-current need as does a vacuum-tube volt-



meter for high-sensitivity voltage measurements. Instrument has input resistance of 50 ohms; sensitivity is 1 microamp. full scale, and input can be overloaded by currents as high as 0.25 amps. without damage. Instrument is not sensitive to position or vibration as are galvanometers. It combines characteristics of a magnetic amplifier with those of a vacuum-tube output circuit to provide low input resistance, high sensitivity and input overload safety. Instrument can be used to activate a

Equipment for Strain Recording



Illustrated is a complete 12-channel portable laboratory for precision strain determination from static strain to a frequency of 5000 cycles per second, using resistance gages that are attached by cement to the points of strain.

In the field or in the laboratory...on a high-speed locomotive or in the air...HATHAWAY strain recording equipment is ideal for the recording of STATIC AND DYNAMIC STRAIN in structural members and machines in operation.

Complete with all necessary balancing controls and monitoring instruments, precision calibrating device, power supply equipment and oscillator, and type S8-B Oscillograph.

TYPE MRC-15 12-element Strain Gage Control Unit. Fully described in Technical Bulletin SP 195H

Type S8-B 12- to 48-element Oscillograph Fully described in Technical Bulletin SP 165H

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INSTRUMENT COMPANY
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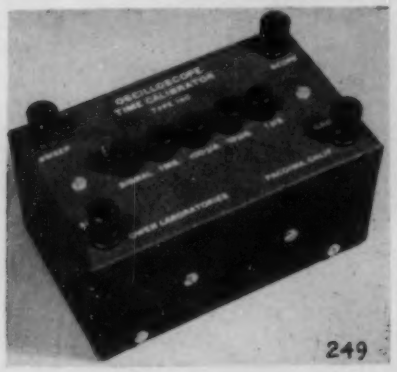
1-milliamp, 1400-ohm recorder directly. Available with multiple ranges.—*W. S. Macdonald Co., Inc., 33 University Rd., Cambridge 38, Mass.*

Mention No. 731 when filling out card.

Oscilloscope Time Calibrator

New "Type 160" time calibrator for use with oscilloscopes introduces images of sine wave crests on 'scope cathode-ray tube so that traces from source



under study can be measured as to their time duration. Instrument requires no separate power source, being attached to sweep output binding post, and to same input as source under study. Calibrator will place "markers" along horizontal axis of sweep in intervals of 1, 10, and 100 kc. and 1 Mc. to measure elapsed time periods of 1 millisecond, 100, 10 or 1 microsecond with accuracy of plus or minus 5 percent.—*Owen Labs., 9130 Orion St., San Fernando, Calif.*

Mention No. 732 when filling out card.

Field-strength Meter

New field strength meter, operating in the range of 200 to 560 kc., is designed particularly for communications and industrial heating fields. It is self-contained and weighs 12.5 lbs. complete

and ready to operate. Field strengths between 10 microvolts per meter and 10 volts per meter are read directly, without recourse to charts, curves, factors, or computations of any kind.—*Clarke Instrument Corp., 910 King St., Silver Spring, Md.*

Mention No. 733 when filling out card.

Instrument Bridger

New "Model 100" bridger enables user to bridge instruments such as vacuum-tube voltmeter, distortion meter or oscilloscope across any part of audio-

frequency circuit through a well-shielded cable without imposing any of load of instruments or cable on circuit. Input impedance is 100 megohms; output impedance is 200 ohms, and output-input voltage ratio is 0.98 up to 30 volts with low-capacitance output circuits and up to 25 volts with usual shielded output cable. Bridger employs cathode follower and new, flexible, low-capacitance, plastic-coated cable.—*Audio Instrument Co., 1947 Broadway, New York 23, N. Y.*

Mention No. 734 when filling out card.

Voltage Divider

New "Model 104" voltage divider, for use with maker's "Model 100" bridger, enables latter instrument to be employed at higher input voltages. Input impedance of divider is 200 megohms, maximum input voltage is 250 volts and ratio of divider is 10 to 1.—*Audio Instrument Co., 1947 Broadway, New York 23, N. Y.*

Mention No. 735 when filling out card.

Power Analyzer

New "Model 90-A" a-c. power analyzer permits measurements of volts, watts and amps. in single or polyphase circuits with an accuracy of 1 percent (up to 133 cycles). Frequency range is 25 to 133 cycles, which can be extended to 400 cycles by use of small correction factors. From data obtained, power factors and rkva also can be determined. Current rating is 1.5 amps. full scale

to 150 in overlapping ranges. Voltage range is 150, 300 and 600; power range is 150 to 120 kw.—*Niagara Electrical Instruments Co., 559 Ellicott St., Buffalo 3, N. Y.*

Mention No. 736 when filling out card.

High-speed Centrifuge

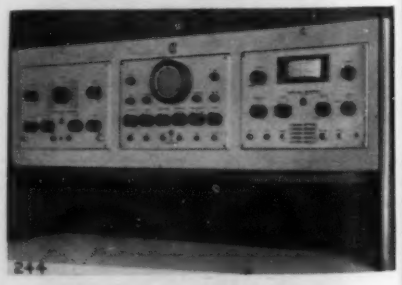
New "Model L Spinco" is a preparative centrifuge for subjecting samples to centrifugal forces as high as 125,000 times that of gravity. Its employs various sizes of rotors from 6.75 to 11 in. in

diameter, capable of holding samples of 150 to 1100 ml. Force exerted is 125,000 G on 150 ml. sample at 40,000 rpm. and 60,000 G on sample of 1100 ml. at 20,000 rpm. Entire unit is housed in protective armor-steel guard 1.5 in. thick and 2-stage mechanical pump creates usable vacuum within 5 minutes from start. Rotors attain maximum speed in 4 to 20 minutes. Safety and operating features include automatic control limits for motor current, automatic governor, automatic braking and time switch.—*Specialized Instruments Corp., 656 O'Neill Ave., Belmont, Calif.*

Mention No. 737 when filling out card.

Test-equipment Rack

New "Model WS-172" test equipment rack offers means for attractive assembly of maker's test instruments for servicing TV, FM, PA and other electrical equipment. New model accommodates



any three test instruments and has removable front panel for easy interchanging or removal of units. Rack is 21 in. high, 48 in. long and 12 in. deep including space of 7 in. below mounted instruments. A suggested combination for TV servicing includes maker's sweep

generator, oscilloscope and calibrator.—*Tube Dep't, Radio Corp. of America, Harrison, N. J.*

Mention No. 738 when filling out card.

Timing-mark Generator

New 1,000-cycle pulse generator, for use with high-speed "Fastax" cameras, exposes timing marks at 0.001 second

intervals on film. Unit incorporates 100,000-cps. crystal oscillator and two of maker's decade counters. Generator can be employed with as many as 14 cameras simultaneously, or with 14 argon-glow lamps of 0.25 watts. Can be used with 50, 60 and 400-cycle current of 110 volts.—*Potter Instrument Co., 136-56 Roosevelt Ave., Flushing, N. Y.*

Mention No. 739 when filling out card.

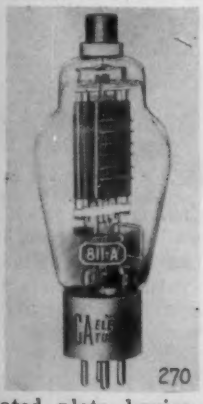
Voltage Dividers

New "Models F and G" voltage dividers are laboratory instruments of single-turn 360-deg. continuous-rotation type which feature long life, low noise, extreme angle of rotation and accuracy of setting. "Model F" has an electrical rotation characteristic of 359 deg. while that of "Model G" is 356 deg. Linearity accuracy of "Model F" is plus or minus 0.5 percent. Operating torque of "Model F" is 1.75 oz.-in. and for "Model G" it is 0.8 oz.-in.—*Helipot Corp., South Pasadena, Calif.*

Mention No. 740 when filling out card.

Power Triode

New "811-A" power triode—an improved version of "811"—utilities a modified construction featuring a zir-



conium-coated plate having radiating fins to give greater dissipation capability, grid and plate leads designed to have low r-f. loss, and a greatly strengthened top-cap assembly with ceramic

$1,500 inventory abolished — at a cost of $4.46!

With more than 700 vacuum tubes needed by industry, a tube distributor would find profits consumed by 100% inventories. But by ordering tubes as needed via Air Express, he holds stocks to 25%. Example: Orders $1,500 tube at 9 A.M. from supplier 900 miles away. Delivered to customer 6 P.M. same day. 16 lbs.: cost, $4.46.

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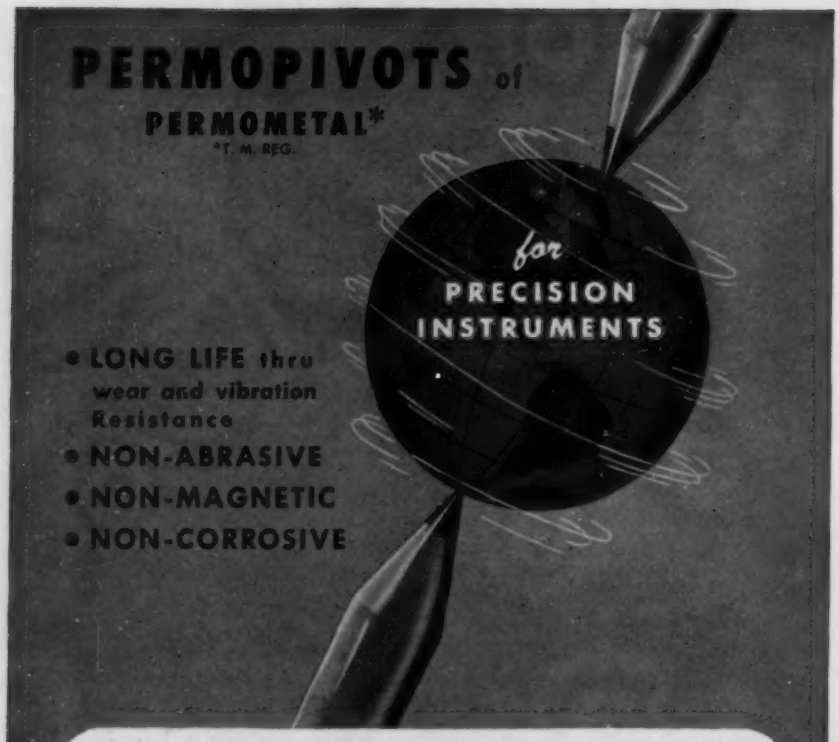

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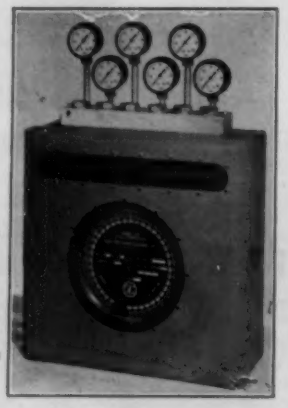

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collar. Because of its high permeance, it operates at high efficiency and with low driving power. Operation with maximum ratings is permissible up to 30 Mc. and with reduced ratings to 100 Mc.—*Tube Dep't, Radio Corp. of America, Harrison, N. J.*

Mention No. 741 when filling out card.

D-c. Power Supply

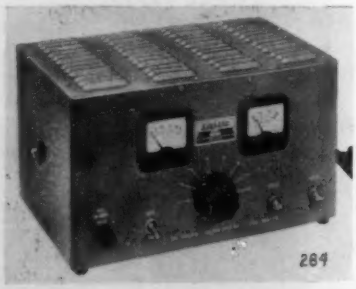
New "Model 245" power supply is said to be first to provide exceptional degree of regulation in small, compact unit. It provides d-c. output of 200 to

245 volts at 0 to 200 milliamps. regulated; a-c. output of 6.3 volts at 6 amps. unregulated. Regulation between 200 and 450 volts for both load variations from 0 to 200 milliamps. and input variations from 105 to 125 volts is said to be less than 0.5 percent. D-c. voltage output is regulated within 0.5 volts between 200 and 450 volts for load variations of 0 to 200 milliamps.; ripple of less than 5 millivolts is claimed. Panel incorporates voltage controls, output terminals and indicators for direct readings of d-c. milliamps. and voltage. —*Kepco Labs., Inc., 149-14 41st Ave., Flushing, N. Y.*

Mention No. 742 when filling out card.

D-c. Power Supply

New "Model B" power supply is claimed to be most efficient on market owing to design features including use of new heavy-duty selenium rectifiers with wide-range variable control,

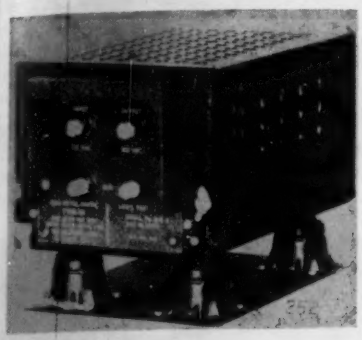


damped volt- and ammeter, 8 power tap switches. Instrument delivers 3 to 9 volts with rating of 6 volts at 20 amps. continuous and 35 amps. instantaneous. It is primarily designed for testing radios and also is useful for testing faulty vibrators, push button solenoids, etc. Its low ripple (3 percent a.c.) is said to equal storage battery in performance.—*Electro Products Labs., Inc., 549 W. Randolph St., Chicago 6, Ill.*

Mention No. 743 when filling out card.

D-c. Power Supply

New "Model 30" d-c. power supply is stated to provide unusually good control and minimum size in an instrument weighing only 8 lbs. Converter has no



moving parts, is usable at high altitudes and at high temperatures; also is resistant to salt spray, fungi, etc. Input is rated at 110 to 120 volts, 380 to 420 cycles, single phase; output rating is 300 volts d.c., 0 to 400 milliamps. Instrument meets USAF specifications for Type E-1 static converters.—*Varo Mfg. Co., Inc., Box 638, Garland, Texas.*

Mention No. 744 when filling out card.

D-c. Power Supply

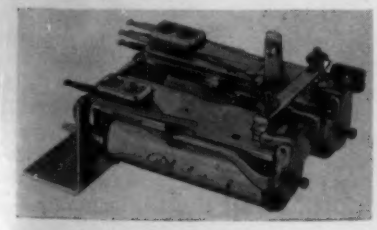
New "Model A" power supply is said to provide d-c. voltages regulated within 1 volt from 0 to full load and under line variations of 105 to 125 volts. Rip-

ple of less than 10 millivolts is claimed at full load with 115-volt input. Instrument is said to be unusually stable—within 1 volt over long periods of use at full load. It is furnished in cabinet as illustrated or for panel mounting.—*Howard Co., 934 Argyle Road, Drexel Hill, Penna.*

Mention No. 745 when filling out card.

Interlocking Relays

New "Series 30500" interlocking relays incorporate two of maker's "Type 2 Phil-trol" relays so that when one is energized, a spring catch is automatically locked in position. Release relay, when energized, automatically unlocks



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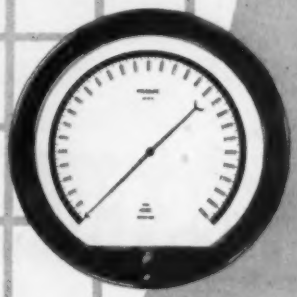

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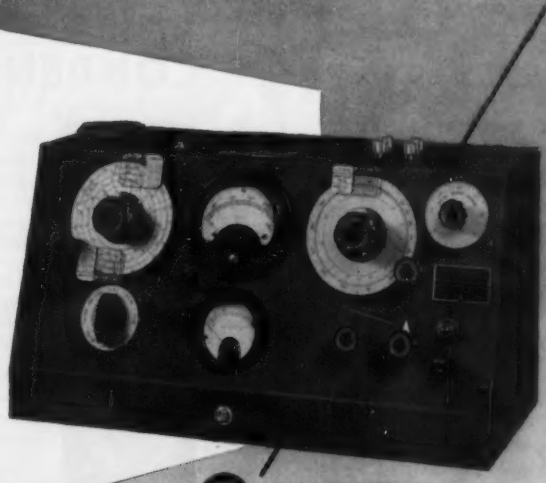

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The 160-A Q-Meter is unexcelled for laboratory and development applications, having received world wide recognition as the outstanding instrument for measuring Q, inductance, and capacitance at radio frequencies.

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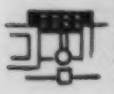

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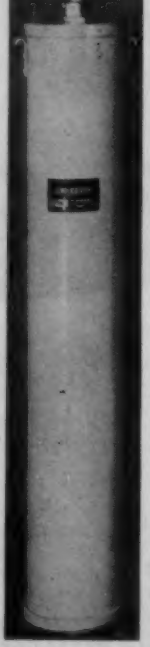

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armature. Relays are furnished for either a-c. or d-c. operation, may be equipped with as many as 12 springs, and d-c. types can be furnished with copper slug coils to slow action. Both s-p. and d-p. types are available with contact ratings up to 6 amps., 110 volts a.c.—*Phillips Control Corp., Joliet, Ill.*

Mention No. 746 when filling out card.

Hermetically-sealed Relays

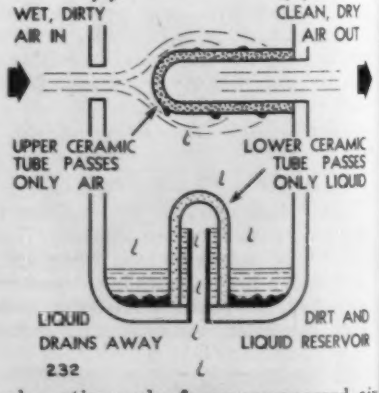
New line of hermetically-sealed relays features operating dependability due to manner of sealing in dry, inert atmosphere which is said to protect

parts from moisture, ice, dust, fungi and varying atmospheric pressure. Metal housing is tamper-proof and can be had in various shapes and sizes to accommodate one or more relays. Types vary for operation from a fraction of a volt to several hundred volts, and with contacts rated at a few milliwatts to several hundred watts. Relays also can be supplied to operate in 1 to 100 milliseconds and to release in 5 to 500 milliseconds.—*Automatic Electric Sales Corp., 1033 West Van Buren St., Chicago 11, Ill.*

Mention No. 747 when filling out card.

Instrument-air Cleaner

New "Liqui-jector" removes water and water-oil emulsions automatically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CLEAN, DRY AIR OUT
UPPER CERAMIC TUBE PASSES ONLY AIR
LOWER CERAMIC TUBE PASSES ONLY LIQUID
LIQUID DRAINS AWAY
DIRT AND LIQUID RESERVOIR
232

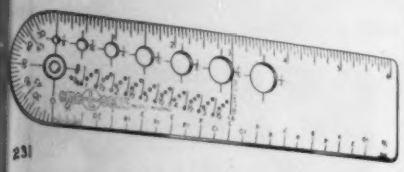
and continuously from compressed air or gas lines. Phase separation and liquid ejection are accomplished by two ceramic tubes; one water-repellent, the other water-permeable but air-impervious. Compressed air or other gas passes through the first tube where it is stripped of its aqueous contamination

and dirt. Moisture drops to bottom and drains through second tube without loss of air. Water ejection rates for three sizes vary from 0.5 to 2.5 gallons per 24 hours. "Liquijector" acts as a filter, removing atmospheric dirt and solid particles 100 microns or even less in diameter. Housing is cast bronze. There being no moving parts, maintenance is limited to periodic inspection and removal of accumulated dirt.—*Selas Corp. of America, Erie Ave. & D St., Philadelphia 34, Pa.*

Mention No. 748 when filling out card.

Combination Drawing Instrument

New "Circ-l-Scale" is a vest-pocket-size drawing instrument combining compass, protractor, square, scale, let-



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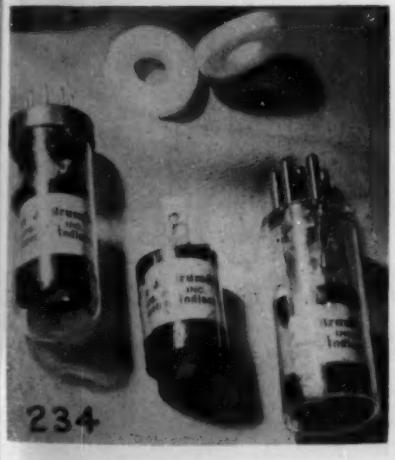
tering device, and means of cutting mimeograph stencils. Instrument is formed of "Anderolite" plastic which is said to have rigidity and wearing qualities of steel. Graduations and lines are pressed into plastic hydraulically from dies said to be accurate to 0.0002 in.—*L. A. Cuson, 9100 Roselawn Ave., Detroit 4, Mich.*

Mention No. 749 when filling out card.

Midget Relay

New "Model SM" midget relay is said to be first in which miniaturization is accomplished by departing from conventional design. All magnetic-circuit elements perform multiple functions, permitting size to be 0.625 in. in diameter by 1.3125 in. long. (Photo shows comparison with candy drops.) Relay weighs 0.5 oz., is available with windings to 3400 ohms, permitting operation to 75 volts d.c., and has minimum sensitivity of 5 milliamps. at 80 milliwatts. Maximum coil dissipation of new relay is 1.75 watts at 83 C. temperature rise. Pure silver contacts are rated at 1 amp.



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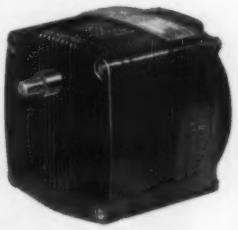

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The Bodine Type K Motor is a dependable source of small power, 1/2000 to 1/750 horsepower. It is available with or without speed reducer, speeds as low as 1 rpm. Compact . . . 2⅜" square. Used in such instruments as pyrometers, sequence or cycle controllers, timers, and other instruments where reliable operation is essential.

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for 50,000 operations and at 0.25 amp. for continuous operation with 110-volt 60-cycle a.c.—*Potter & Brumfield, 549 West Washington Blvd., Chicago 6, Ill.*

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Split-core Transformer

New "Type 941" split-core transformer is designed particularly for use with maker's "Model 90-A" power analyzer, extending latter's range by 400 percent. Instrument is available in two ratings: 75-600 amps. or 100 to 1,000 amps. Core material is of special type which is said to permit measurements of true power. —*Niagara Electrical Instruments Co., 559 Ellicott St., Buffalo 3, N. Y.*

Mention No. 751 when filling out card.

Valve Selecting Computer

New valve selector enables user to order valves by means of code numbers given for more than 35,000 standard valves. Selector is made on principle of foreign language "verb wheel" so that various types of valves can readily be found. Requests (on company letterheads) for selector are invited.—*Valvair Corp., 454 Morgan Ave., Akron 11, Ohio.*

Mention No. 752 when filling out card.

Draftmen's Template for Ellipses

New "No. 77 Ellipse Master Template" is said to have time-saving features not found in any other template,

such as true isometric ellipses projected from an angle of 35°16', allowance for pencil point to facilitate accuracy and drafting speed, sixty ellipses compactly grouped to allow a wide range of sizes yet maintain a handy working-size template (length, 10.43 in.). It is applicable to all axonometric drawing. Each ellipse is milled from 0.030 mathematical-quality plastic material to engraving-machine accuracy. — *Rapidesign, Inc., P.O. Box 592, Glendale, Calif.*

Mention No. 753 when filling out card.

D-c.-to-A-c. Chopper

New 60-cycle chopper added to maker's line (see other models in recent issues) provides modulation-de-

modulation in one unit, being a d-p.d-t unit lower in cost and more compact than two s-p.d-t units. Also, it has coil leads brought out at top through a detachable connector.—*Stevens-Arnold, Inc., 22 Elkins St., South Boston, Mass.*

Mention No. 754 when filling out card.

TECHNICAL SOCIETIES

Northern California Instrument Association

The Northern California Instrument Association at its annual meeting held at the Claremont Hotel, Berkeley, California, June 20, elected officers for the year 1949-1950: C. S. Beard, Bechtel Corp., *President;* Keith Draeger, Standard Oil Co. of Calif., *Vice President;* M. A. Dimmick, Mare Island Navy Yard, *Secretary and Treasurer.*

Feature speaker of the evening was Dr. W. J. Warren, Professor of Electricity and Electronics at Santa Clara University, who spoke on "The Field of Electronics in Instrumentation."

Approximately 75 leaders in the Instrument Field in Northern California were present.

GILBERT T. BOWMAN,
Chairman, Publicity Committee.

Biological Photographic Association

The 19th Annual Meeting of the Biological Photographic Association will be held in Cleveland, Ohio, on Wednesday September 7th, through Saturday noon September 10th, at the Hotel Cleveland.

A well rounded scientific program is being assembled by Dr. Oscar Richards, American Optical Co., Buffalo 15, N. Y., and Thomas J. Lannon, 1528 Starkweather Ave., Cleveland 13, Ohio. Suggestions are welcome.

Salon entry blanks may be obtained from William Stevenson, Mt. Sinai Hospital, 1800 East 105th Street, Cleveland 6, Ohio.

The preliminary agenda calls for one afternoon to be spent at Nela Park where the latest in lighting will be demonstrated.

For further information contact Convention General Chairman David Lubin, 130 Keats Lane, Berea, Ohio, or Publicity Chairman David G. Shields, 2400 Overlook Road, Cleveland Heights 6, Ohio.

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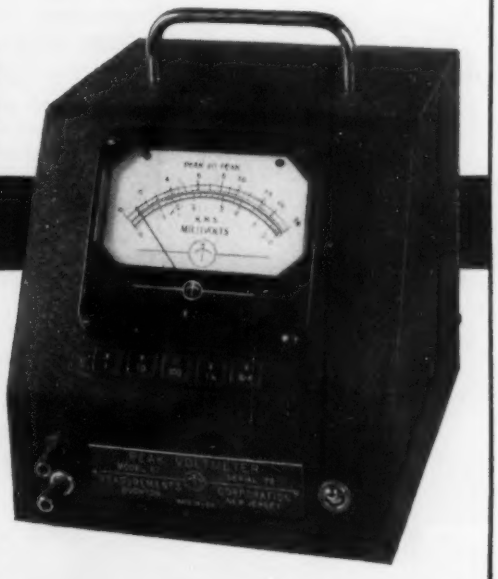

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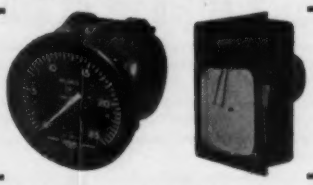

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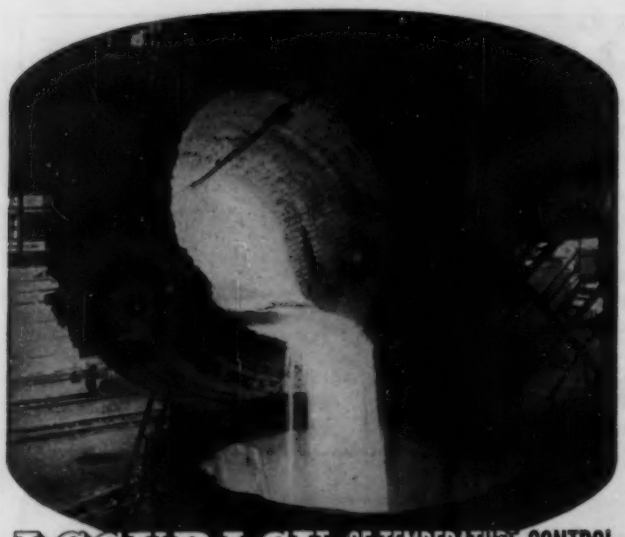

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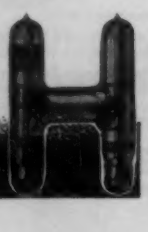


EPLAB Standard Cells

Application Factors in pH Control

(Continued from page 587)

ately after the screen and regulate the addition of control reagent to a small 50-gallon mixing box.

A 500-gallon auxiliary circulating tank feeds recirculated white water into the control loop *independently* of the control valve. The contents of this tank are equally as effective as the control valve in changing pH of the control loop and, since its period is entirely different from and out of phase with the regulator, it is utterly hopeless to attain any degree of acceptable regulation unless the buffer index is so low that automatic regulation is unnecessary in the first place. Fig. 23 illustrates the trend of control obtained from this installation.

The lower illustration of Fig. 22 represents how the process was redesigned to eliminate the two defects involved in the above installation. It is to be noted that all effects of pH regulation are contained within a single residence system equipped with an agitator and having a retention constant comparable with the reaction rate constant.

It may be argued that if the screen forms a dead pool and affects pH regulation in the first example, what assurance have we that the stock reaching the Fourdrinier wire is uniform? The answer is that the effect of dead pools alters the ratio of retention factor to reaction rate and if the material entering is uniform and completely reacted, it will have no effect on uniformity of regulation. Fig. 24 is an actual chart record of the improved installation.

Equilibrium lag has not been recognized and evaluated by many process control engineers and it sometimes becomes annoying and irritable to the uninitiated. Many control engineers have reported favorable results from some pH control installations and "temperamental" or unexplainable behavior in others. Conventional rules of control analysis have been applied without effect in diagnosing pH troubles, and the idiosyncrasies are usually accepted as "typical characteristics of pH control."

Equilibrium lag may identify itself in a number of ways depending on its type and cause. Chemical inhomogeneity is one of the most frequent offenders and is characterized by an irregular "scratchy" record having no definite period of cyclation as illustrated in Fig. 25. Irrespective of the mechanism of reactions (occlusion, non-reversibility, slow-reactions, etc.) which may produce this effect, it can be removed by either one of two procedures:

1. If the cause is physical non-uniformity of the residence system, there may be:

(a) Improper or insufficient agitation. Large slow-speed agitators which revolve the tank contents as a mass in one direction are not effective blenders. Tangential agitation which turns the mass over at least two times throughout rate (F) is preferred.

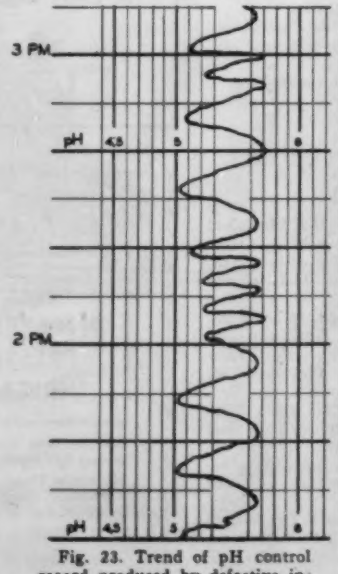


Fig. 23. Trend of pH control record produced by defective installation illustrated in Fig. 22.

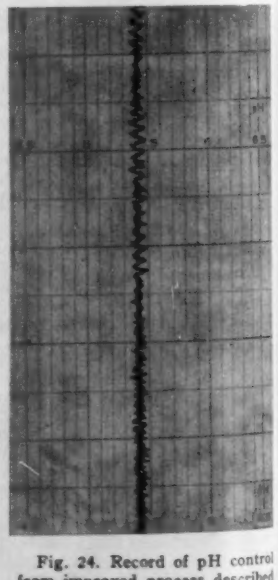


Fig. 24. Record of pH control from improved process described in Fig. 22.

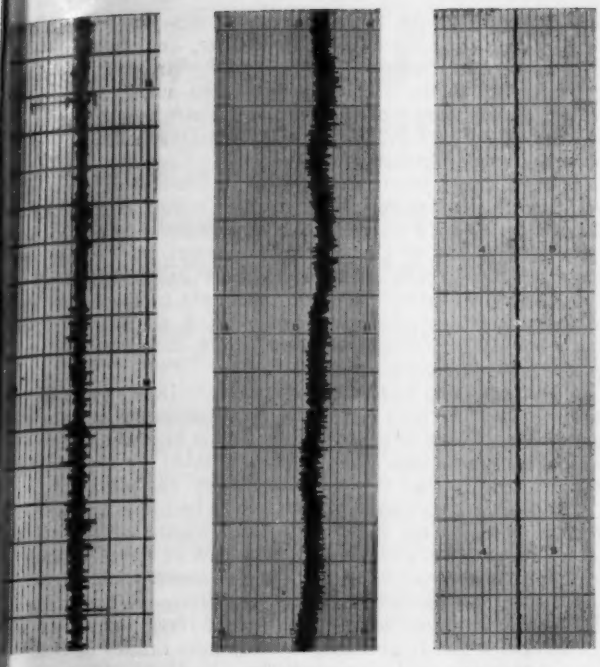


Fig. 25 Fig. 25A Fig. 25B

Fig. 25. Characteristic record resulting from equilibrium lag in control loop of pH control process. Irregular "scratchy" record characterizes incomplete chemical reactions in process.

Fig. 25-A. Typical control chart from process having equilibrium lag present in zone of high concentration gradient. See Fig. 25-B for effect of operation in zone of lower concentration gradient.

Fig. 25-B. Improved pH control resulting from elimination of equilibrium lag by applying control to point of lower concentration gradient in process.

(b) The residence may be short-circuiting excessively because of improperly located reagent feed lines or because of diffusion errors in feed nozzles or because of an over or undersized system. Redesign of the system as given elsewhere in this serial will correct this fault.

2. If the cause is non-equilibrium of chemical reactions, irrespective of physical uniformity, the remedy is *time*.

Chemical reactions are *not* all instantaneous as proclaimed by some "pH experts" and they must be given ample time to reach equilibrium before contact with the electrodes or measuring unit. If the reaction is slow, or if molecular rearrangement occurs, or if flocculation, gelation or occlusion results from reagent addition, detection lag must be *increased* to *decrease* equilibrium lag. If the increased detection lag results in excessive cyclation for a single regulator, it usually is advisable to use cascaded regulators as described elsewhere in this article.

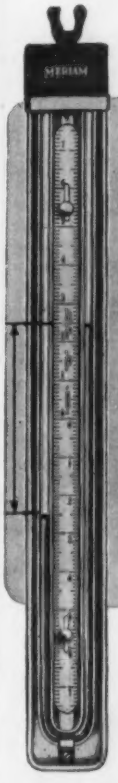
Concentration gradient of the process liquors sometimes has an important bearing on time requirements for equilibrium. High concentration may require more or less time than dilute liquors depending on the nature of the reaction, and "incurable" equilibrium lag in one part of the process may be obviated by relocation of the regulator at a point of higher or lower concentration gradient, whichever gives best results.

In a number of cases the writer has eliminated "incurable" equilibrium lag which otherwise would have required impossible detection lags, by relocating the control at a point of different concentration gradient.

(The writer stresses to the reader, the necessity for, and importance of, analysis of any continuous chemical process as a *distance-concentration* system for a clear understanding of its mechanism and behavior of variables involved, and their bearing on instrumentation requirements).

One typical process, having pH control installed at a point where concentration gradient was 4%, produced the characteristic record of Fig. 25-A — the best control obtainable without cyclation. The inhomogeneity (band width) was independent of control point but widened with decreasing detection lag. It was permissible to relocate the control at a point of lower concentration gradient, and cascaded regulation became unnecessary. The self-evident record (Fig. 25-B) indicates the effect of relocating the control at a point in the process where concentration of active process liquor was 2.5%.

It has been the writer's frequent experience in the paper industry that multiple reagent additions must be in accordance with a definite order to avoid equilibrium lag. Sometimes, sodium aluminate and alum are added simultaneously in separate streams at the machine to produce a heavy floc; either stream may be fixed, with the other regulated to control pH. However, better results have been obtained in



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most cases by fixing the aluminate stream and regulating alum rather than the reverse procedure, and, furthermore, it is usually desirable, from a control standpoint only, to add reagents to the dilute concentration stock corresponding to a consistency of 0.5% rather than the higher consistency (usually 3.5%-4.5%) at the mixing box. More uniform control is obtained.

In most cases where alum feed is fixed and aluminate feed regulated, the resultant control record is not unlike Fig. 25 or 25-A: But, in practically every case of trouble, a rearrangement of the order of reagent feed eliminated the characteristic inhomogeneity. Best results followed a general rule of adding sodium aluminate to the stock first and allowing it several seconds time (usually 30 to 60) to reach equilibrium with the stock before alum addition, and consequent pH control.

It has not been uncommon experience in many cases of single reagent control installations to encounter equilibrium lag with additions of control alum to the high-density stock, which, in every case, has been eliminated by moving the reagent feed line to the low consistency (0.5%) stock.

Many pH control installations are to be found throughout industry having inhomogeneity band widths of 0.5 pH to 1.0 pH or greater, and, because of a lack of complete understanding of the mechanism of the *concentration* variable, and conditions pertaining to its measurement and control, the control engineer is prone to accept irregular results as normal behavior. It probably is a common fallacy in reasoning with many engineers that, "to eliminate pH troubles, one must reduce detection lag as low as possible and add plenty of agitation; if this is ineffective, then it must be

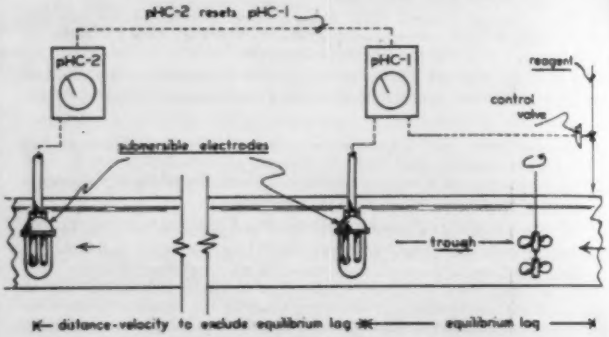

Fig. 26. Cascaded pH regulators applied to open trough process to correct equilibrium lag of single regulator process.

the nature of the beast to behave irregularly." This reasoning may be true except for equilibrium lag which requires *time* for stabilization. If the irregularities cannot be cured with a single regulator, and if it is not permissable to relocate at a different point in the system (a point of more favorable concentration gradient) the problem calls for cascaded regulation.

As a simple illustration of this point, the writer was recently consulted on a pH control problem not unlike the one described in connection with Fig. 19. A copper solution, flowing in an open trough is treated with carbon dioxide to form a complex compound for subsequent treatment in a reactor. Riffler dams and a high speed agitator had failed to improve a control record similar to Fig. 25, and, the control specialist apparently lacking knowledge of equilibrium lag, had recommended the installation of a tank and agitator which would have cost the customer more than his appropriation for the entire control equipment. The writer made tests to determine the required *distance-velocity* or detection lag to produce a stabilized record, but found that this was excessive for a single proportional regulator without introducing sustained hunting. A cascaded system of two series-connected pH regulators, separated with sufficient distance-velocity to stabilize reactions, was found quite effective in maintaining uniform influent to the reactor, and without the need for a costly tank and agitator (see Fig. 26).

Another extremely important form of equilibrium lag makes its appearance when a separator or extractor of some form is included in the pH control circuit and separates, non-linearly, the acid and basic constituents, or

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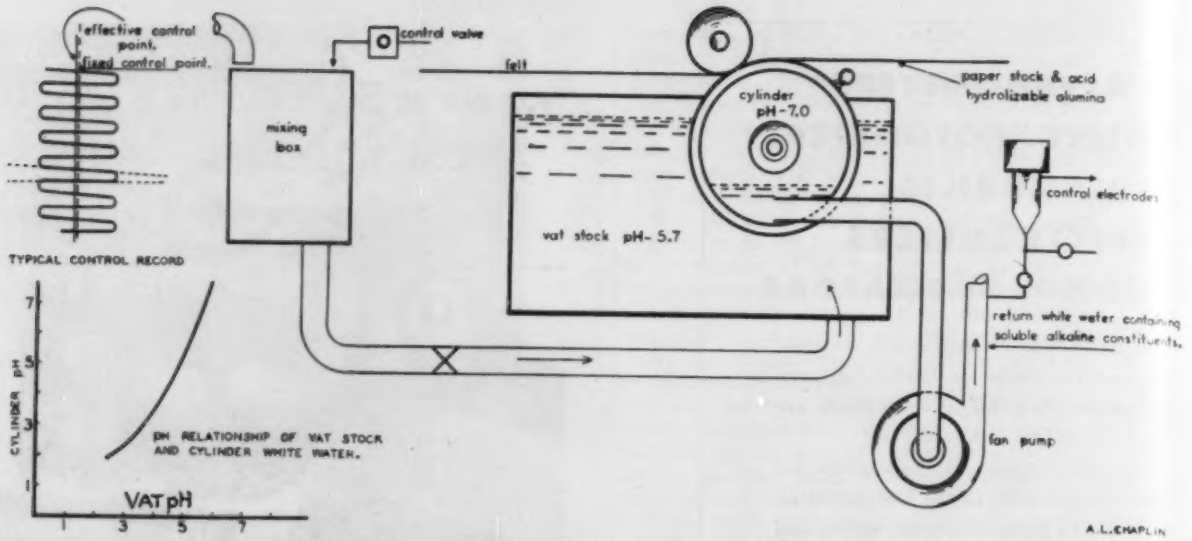

Fig. 27. Schematic illustration of paper-board machine showing conditions conducive to equilibrium lag resulting from separation of acidic and basic constituents of process liquor in control loop.

removes a precipitate or floc having preferential affinity for the acid or basic constituent, either directly or indirectly. Fig. 27 is a schematic illustration of a vat type paper machine which exhibits this effect. Paper pulp is pumped to the vat and forms a mat on the surface of the rotating screen while the suspending water passes through the perforations and out to the fan pump to be recycled in the process. The pulp mat is transferred to an endless felt blanket which passes over the cylinder and is held firmly against its surface by a press roll.

The pulp fibres have a preferential affinity for the acid constituent of the white water while the alkaline constituent passes through the cylinder to the fan pump. Because of this separation, the relationship between cylinder pH and vat pH is not linear, but follows a relationship as indicated by the lower left graph of Fig. 27. Control records obtained under such conditions are not symmetrical, and pH measured at the fan pump is not indicative of vat pH under any condition unless established conversion factors are known and are constant. If the process is one having a high buffer index, it will be characterized by instability, and, should the regulator start hunting, the equilibrium lag of the process will aggravate control oscillations and the regulator cannot stabilize without an externally applied force.

Probably the least recognized, and very commonly violated form of equilibrium lag is that illustrated in Fig. 28. This figure represents a schematic plan view of a process consisting of a control retention tank and three parallel-connected process units requiring pH regulation. The fault in this design lies in the location of the electrodes with respect to the individual process units. Each unit has its own respective velocity/distance factor and its own retention/reaction-rate ratio. These ratios are not equal for all three units because (1) the hold-up of one unit may be larger than the other and (2) the distance-velocity paths from the control valve to the electrodes through each respective unit are not equal. The natural periods of oscillation of the three individual process units are unequal, and unless they are related in exact phase quadrature, it will not be possible for the system to reach equilibrium and stability at the electrodes. Should the pH load change or the throughput rate vary, the system will start hunting and will persist until halted by outside forces.

The best way to visualize such conditions in this or any other similar process is by analysis from the basic concept that a continuous process is a *distance-concentration* system. The concentration of constituents remain constant at any one designated point in the system but change with forward displacement of materials. By visualizing the concentration gradient as a sine wave leaving the control re-

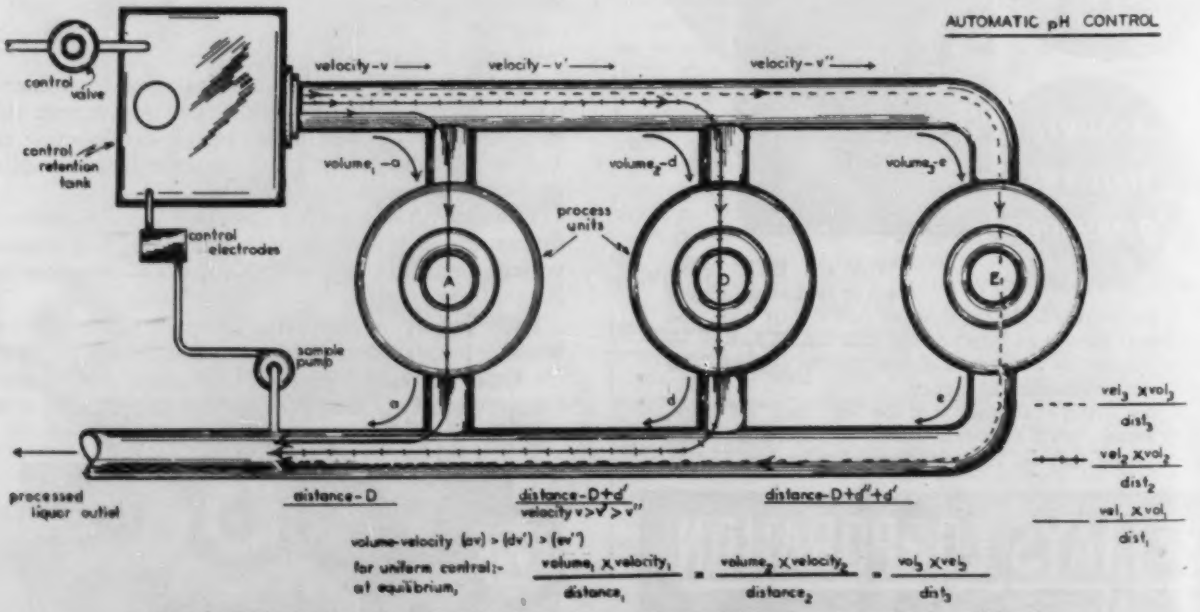

Fig. 28. Schematic illustration of process layout incorporating equilibrium lag as a result of parallel units having different reaction constants and for velocity-distance components in control loop.

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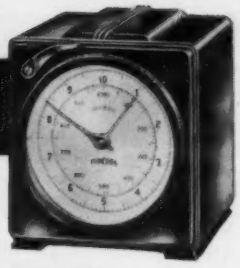

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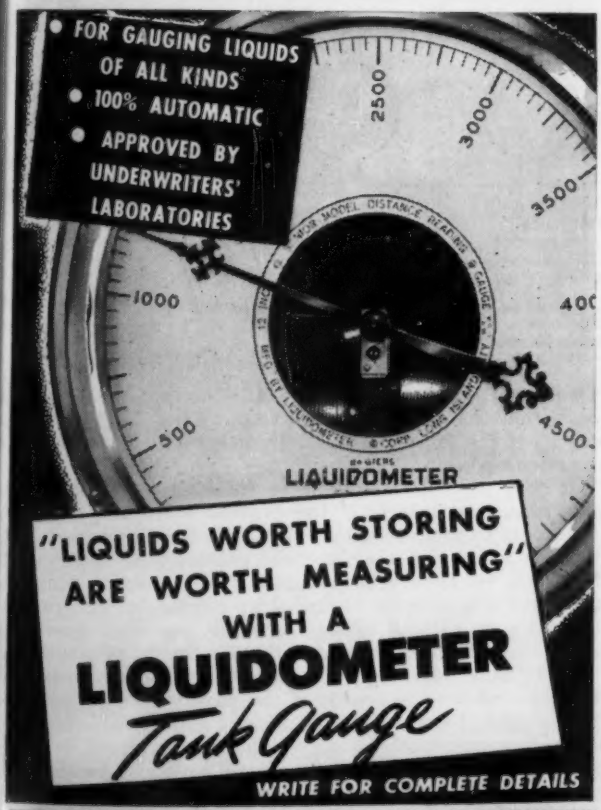

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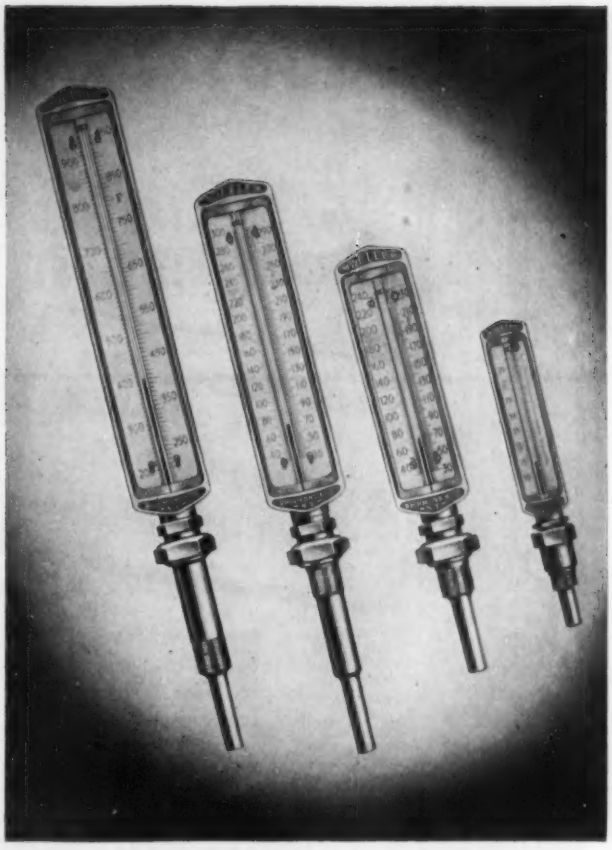

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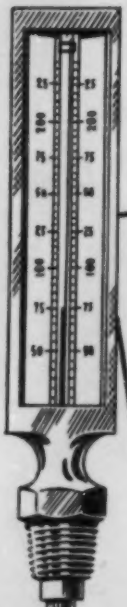

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tention tank and moving forward along the main header, it is obvious that its period is altered at each branch "take-off," and reactions will not have reached the same degree of equilibrium at the common point of rejoining the individual flows. To avoid this type of equilibrium lag, the process must be designed to eliminate split flows in the control loop unless the time constants of the parallel paths are equal.

A modification of this fault has frequently been encountered in parallel installations of continuous separators, and may also be found in similar installations of other process units. The principle applies regardless of the nature of the processing units; and location of the control valve, with respect to the electrodes, should encompass all process units of the control loop in symmetrical order. The unsymmetrical arrangement given in the upper illustration of Fig. 28-A has not been found satisfactory in most cases because of in-

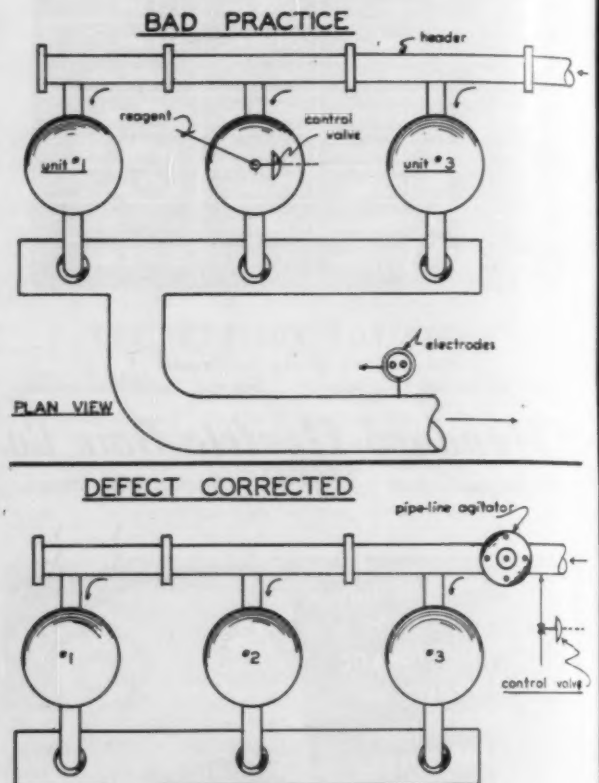

Fig. 28-A. Defective control installation having unequal distribution and equilibrium lag. Defective installation corrected in manner illustrated in lower diagram.

equality of treatment in the parallel units: Rearrangement in symmetrical order, as given in the lower illustration, has corrected the fault in practically every case of the writer's experiences.

It may not be objectionable in some cases to violate this rule, particularly if the process units are of such a nature as to produce little effect and if the nature of reactions is rapid and they are not possessed of chemical inhomogeneity. It may be possible in such cases to overcome excessive retention by means of an unsymmetrical installation. It goes without saying, however, that such provisions apply only if pH is regulated for the benefit of subsequent process units, and cannot be expected to be effective if pH is regulated for the benefit of the parallel processing units in the control loop.

Few process control engineers have experienced or recognized *equilibrium lag* in their control problems because it is peculiar mostly to *concentration* measurements and does not make its appearance so frequently in other types of control. It is an extremely important variable in pH control and the writer has purposely devoted much space to it to accquaint the engineer with its behavior and to stress its importance.

(To be continued)

JOURNAL of the Instrument Society of America

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Vol. 4 — JULY 1949 — No. 6

General News

New Section Officers

This being the season when many sections elect new officers, several have sent in their lists without any news of recent meetings. Others have done both. For ease of reading the names of all new officers are listed in the following rather than in the Section News.

Central Illinois: Pres.—E. H. Fiedler; Vice-Pres.—E. G. Smith; Secretary—H. F. Lange; Treasurer—R. Isenberg.

Montreal: Board of Directors—R. M. Brown, J. Hillen, M. Peart.

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ISA Spring Meeting

The 1949 ISA Spring Meeting was held at the Royal York Hotel, Toronto, Ontario on May 12th and 13th, 1949. 181 Instrument minded men attended the meeting and heard the following papers presented:

Unit Start-Up and What They Can Teach the Instrument Engineer by W. J. Graeb — Imperial Oil, Sarnia, Canada.

Instrumentation of a Typical Chemical Process by C. W. Hills — Shawinigan Chemicals Ltd., Shawinigan Falls.

What Management Expects of an Instrument Department by L. D. Dougan—Polymer Corp.

Instrument Department Organization in Process Industries Panel Discussion:
Chairman — R. J. S. Pigott.
Members of the Panel: Miss Louise Suckfield, Mr. Ralph Webb, Mr. Jim Kerley, Mr. J. Johnston Jr.

Humanities in Instrumentation by E. T. W. Bailey — Steel Co. of Canada.

A Novel Liquid Chlorine Depth Gauge by E. W. Leaver and G. A. Rice.

Considerations in the Application of Instruments to Pulp and Paper Processes by R. M. Brown — Stadler Hurter & Co.

Instrumentation in the Pulp and Paper Industry Panel Discussion. Chairman — J. N. Franklin.

125 attended the ISA Dinner on Thursday evening and heard Mr. B. K. Sandwell, noted Canadian author, lecturer and editor speak.

REGISTRATION: Total 181
137 ISA Members
44 Non-Members
88 Canadians

The following papers are in the hands of Ralph Batcher:

(1) Unit Start-Up and What They Can Teach the Instrument Engineer by W. J. Graeb.
(2) Instrumentation of a Typical Chemical Process by C. W. Hills.
(3) Humanities in Instrumentation by E. T. W. Bailey.
(4) A Novel Liquid Chlorine Depth Gauge by E. W. Leaver and G. A. Rice.
(5) Considerations in the Application of Instruments to Pulp and Paper Processes by R. M. Brown.

Who's Who in ISA

Mr. J. W. Head, president of the Detroit Section, was awarded an Honorary L.L. Degree by Piedmont College, Demorest, Georgia at commencement exercises June 5th. Mr. Head, president and founder of Electronics Institute, Inc., Detroit and also directs the activities of Industrial Electronics, Inc., a consulting organization. He attended Piedmont College for 3 years and graduated from Oglethorpe University in 1935. He became a consultant soon after graduation and later was associated with Dr. Lee DeForest.

J. W. Head

Electronics Institute, Inc., is a radio and television school having a present enrollment of approximately 800.

Pre-Conference Instrument Maintenance Clinic

Those interested in maintenance have the unusual opportunity to receive 20 hours of instruction on maintenance of the latest instruments of selected instrument manufacturers. The Clinic will be held at the Statler Hotel, St. Louis, on Friday, Saturday and Sunday, September 9, 10, and 11, the three days immediately preceeding the opening of the 1949 Instrument Conference and Exhibit. Clinic students can thus attend the Show on Monday and return home with a minimum of time off from their jobs. Exceptionally low hotel rates at the Statler have been arranged. Travel groups on chartered busses are being arranged to keep transportation costs down. Group air transportation is being arranged. Free entertainment for the Clinic students will be provided on Saturday night, September 10th by the St. Louis Section. The National Office can supply detailed information on travel accommodations for your Section.

Section News

BOSTON

The Boston Section held its second annual dinner and dance on Wednesday evening, May 25th, at the Colonnade Room, Hotel Buckminster, Boston. There were thirty-five couples present for dinner, which was served at 7:30 PM. After dinner a brief case was presented to Mr. E. R. Hoffman, the retiring president of the Section. Dancing was enjoyed until 12 P.M. The next meeting of the Section will be held the last Wednesday in September.

—J. H. Condon, Corr.

CALIFORNIA

The June 7th meeting was held at the University Club in Pasadena, with sixty-one members and guests attending the dinner and an additional group of twenty arriving later for the technical session.

Our President, Dr. A. O. Beckman, reported on proceedings of the recent Toronto Conference, following with an outline of plans formulated there for the St. Louis Conference and Exhibit. Due to the number of our Officers and Members planning to attend the St. Louis Convention, and conflict of dates with our Section schedule, the Section voted to hold no local meeting in September.

Mr. Norman Reuel of North American Aviation presented a slide illustrated talk on "Instrumentation Problems in the Synchronization of Liquid-Propellant Rocket Power Plants." Questions and discussions pointed up the problem encountered thru use of corrosive acids and liquid gases as fuels.

In intermission between papers, Mr. Dag Hartman, Chief Electronic Engineer of Swedish Aircraft Co., was introduced by Mr. Willard Young of Consolidated Engineering Corp. Mr. Hartman spoke briefly on his activities and outlined Sweden's current trends in Aircraft Flight Instrumentation.

Mr. Tom Wiancko of the Wiancko Engineering Co. presented a paper on "Application of Variable Reluctance Instruments for Static Testing of Rocket Power Plants." Mr. Wiancko illustrated his paper with slides and demonstration instruments. The next meeting is scheduled for Tuesday, October 4th.

—Chris Wagner, Corr.

KANSAS CITY

The Kansas City Section held an unusual meeting at the University of Kansas City Medical Center, Kansas City, Kansas. Hampton W. Shirer, M.D. presented an illustrated talk on "An Impedance Guaging System for Cardiovascular Pressure Measurement". In addition to the talk, Dr. Shirer showed the members the actual equipment which was developed through the cooperative effort of the electronics laboratory and the Hathaway Instrument Company of Denver, Colorado. The pressure elements were un-

(Continued on page 626)

SEE ARTICLE ON NEXT PAGE

The Author

Mr. Bradner received his BS degree in Physics from Massachusetts Institute of Technology in 1938. Following graduation he was engaged in Instrumentation research for Champion Paper & Fibre Co. and later on

Mead Bradner

pressroom trouble shooting for R. R. Donnelly & Sons. From 1940 to 1943 he was doing Ordnance Design at the Naval Ordnance Laboratory and was Ordnance Engineering Consultant for Westinghouse from 1943 to 1945. Since 1945 he has been Research Engineer with Foxboro Company.

Pneumatic Transmission Lag*

By MEAD BRADNER

As more industrial plants are finding it economical to centralize their process instrumentation, knowledge of the quantitative values of lags in long pneumatic transmission lines becomes increasingly important. It is the object of this paper to present in as usable a form as possible the characteristics and values of the lags due only to the tubing. No attempt has been made to evaluate the effect of these lags on automatic control systems. In obtaining the lags three different types of air pressure disturbances have been introduced into one end of the tubing and the responses at the other end measured.** The first (and most commonly used test method in the instrument industry) consisted of a sudden change from one pressure to another (step upset). Because of the fact that the lags determined this manner depend greatly upon magnitude, midpoint and even direct of the upset considerable doubt is ra as to the suitability of this method investigating lags. In the second me od used, the input pressure was chang at a constant rate (constant rate turbance). This condition comes m closer to actual industrial process c ditions. It was found that the lags termined for a given length and size tubing were independent of direction rate of upset. The third method c sisted of introducing a sinusoida varying input pressure (sinusoidal turbance) in order to provide freque cy response characteristics for use men trained in that approach. Leng up to 2000 feet of three sizes of t ing were used: .125" I. D., .188" I. (Commercial ¼" O. D.) and .305" I. (Commercial ⅜" O. D.). Care was tak to reduce the effect of sources and t minations to an insignificant point that tubing characteristics only w measured. Although the effect of th lags on control systems was not inves gated, an actual transmission syst (Foxboro M/42 Transmitter-Receive was tested to determine the charact istics of a typical commercially ava able remote recording system.

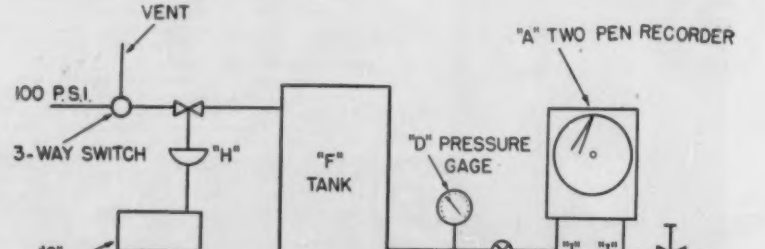

Fig. 1. Step upset apparatus.

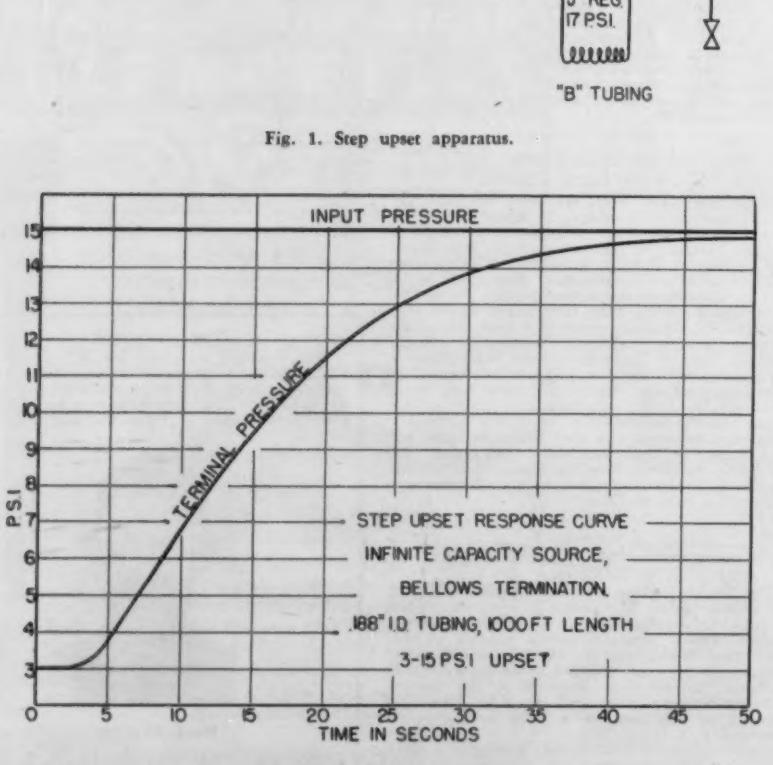

Fig. 2.

Step Upset

Because the data given in the lit ature on this type of upset did not se to check theoretical considerations, tensive tests were made to determine actual response under various con tions. Fig. 1 shows the apparatus u for the step upset tests. After the t ing had been equalized at one pressu an "infinite capacity" supply at anot pressure was suddenly connected to end of the tubing. A two-pen Recor gave records of pressure at both e of the tubing. Appendix A describes apparatus in detail and the proced for running the tests. Fig. 2 show typical curve of the pressures at the put and terminal ends of a long tra mission line with the step upset on input. It will be noticed that the t minal pressure curve has an "S" sh with an initial delay followed by asymtotic approach to the impres pressure. Fig. 3 is a plot of the s data on semi-log paper. If this tra mission system were effectively a sin capacity and resistance (comm

*Presented at the Third Annual Conference of the Instrument Society of America, Sept. 13-17, 1948, Philadelphia, Pa.

Note:—Statements and opinions advanced in papers are to be understood as individual expressions of the authors and not those of the Society.

**In actual practice the position of the mary measuring element is converted in pressure by the transmitter and at the e the transmission line the pressure is reconv to a position of the recording pen. Throug this paper the term "pressure" has been us a convenient way of describing these positi

called a single capacity system) the plot in Fig. 3 would be a straight line such as the dash line. The initial part of the curve deviates greatly from a straight line indicating that the system is not a single capacity one. Referring to Appendix B, one can obtain a more thorough discussion and the evaluation of the constants in the equations describing the cases of 1000 feet, 1500 feet and 2000 feet of .188 I. D. tubing.

Some previous investigators have used the 63.2% point as a significant value in describing the lag in the long transmission lines—implying that the system is effectively a single capacity one.* However, this 63.2% point has questionable significance in other than single capacity systems and therefore must be used with great care.

From a purely experimental point of view three "time constants" have been plotted from the test charts: a 95% value to give an indication of the operation of a Recorder at the end of the line; a ½% value to indicate the delay encountered before any appreciable signal is received; and the classical 63.2% point. These three curves form a consensation of data taken in over 75 tests, and with the characteristic curve, Fig. 3 enable the reader to reproduce any of these 75 odd response curves that have been omitted for the sake of brevity. Fig. 4 gives the three "time constants" for .188 I. D. tubing and Fig. 5 gives the same for .305 I. D. tubing. In Fig. 6 are given the 63.2% values for the three tubings that were used all with 3 to 15 psi upset, with the same source and same termination and therefore identical conditions.

The effect of operating a valve motor directly on the end of the tubing is shown in Fig. 7 for .305 I. D. tubing and in Fig. 8 for .188 I. D. tubing. The volumes of the Foxboro Stabilflo valve motors used are approximately:

	Volumes—Cu. In.	
Motor	3 psi	15 psi
No. 6	25	55
No. 8	105	225
No. 10	200	470

A large number of upsets were used in order to determine the effect on the time constants of variations in conditions. Fig. 9 shows the relation between 63.2% values for .188 I. D. tubing with four arbitrarily selected upsets. In Fig. 10 are plotted the 63.2% times versus the size of the upset for 1000 feet of .188 I. D. tubing and a 9 psi midpoint. Fig. 11 gives the relation of the 63.2% times to the midpoint pressure with 3 psi, 6 psi and 12 psi upsets. It can be seen from the curves in Figs. 9, 10 and 11 that the lag varies with magnitude of upset, midpoint of upset and even with direction of upset so that the information can only be used for comparison—and then only with extreme care to make certain of all of the variables. Due to these conditions and due to the

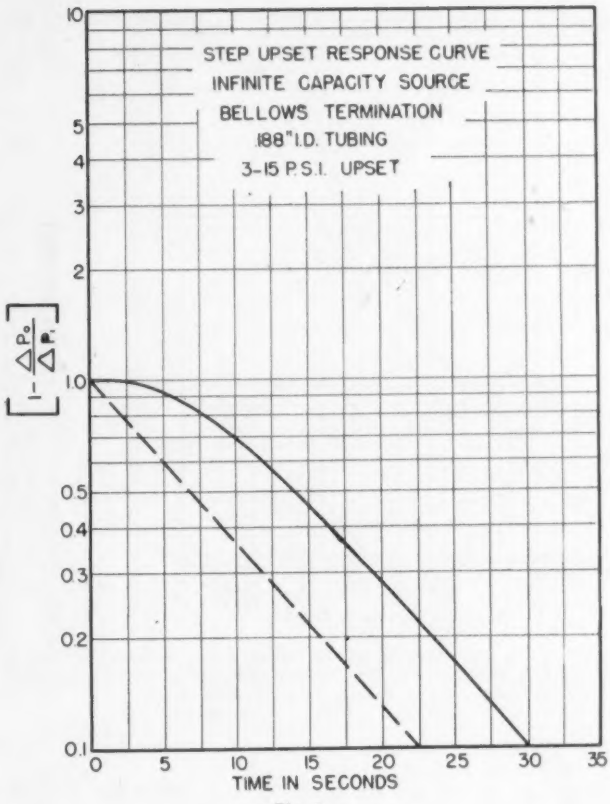

Fig. 3.

*From Appendix B we see that the equation for a single capacity system is $\frac{\Delta Po}{\Delta Pi} = 1 - e^{-\frac{t}{k}}$. At time t=k the equation becomes $\frac{\Delta Po}{\Delta Pi} = 1 - e^{-1}$ equal .632, which means that when Po=63.2% of Pi then k=t.

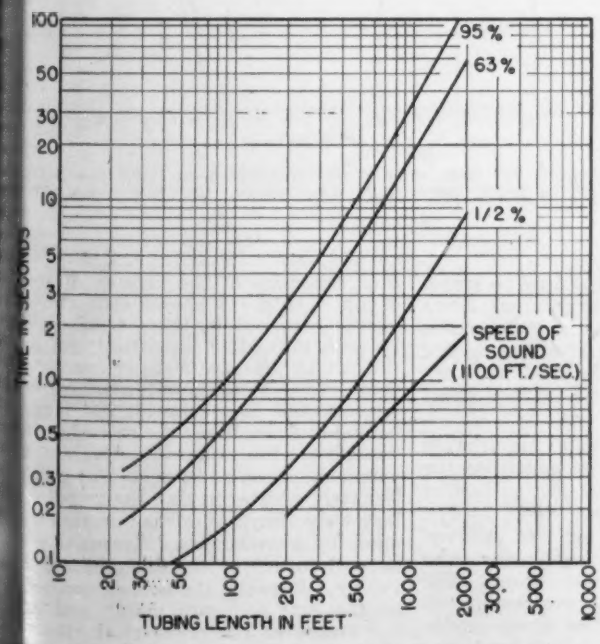

Fig. 4. Step upset, time constants, infinite capacity source, bellows termination, .188" I.D. tubing, 3-15 lbs./in.² upset.

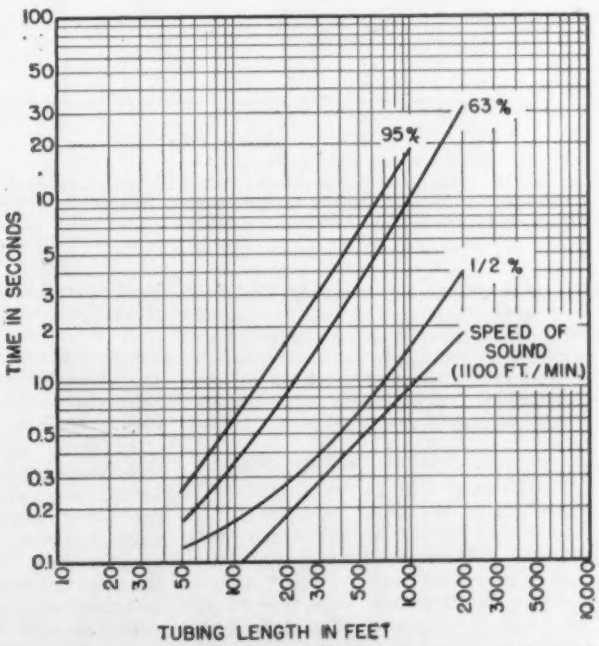

Fig. 5. Step upset, time constants, infinite capacity source, bellows termination .305" I.D. tubing, 3-15 lbs./in.² upset.

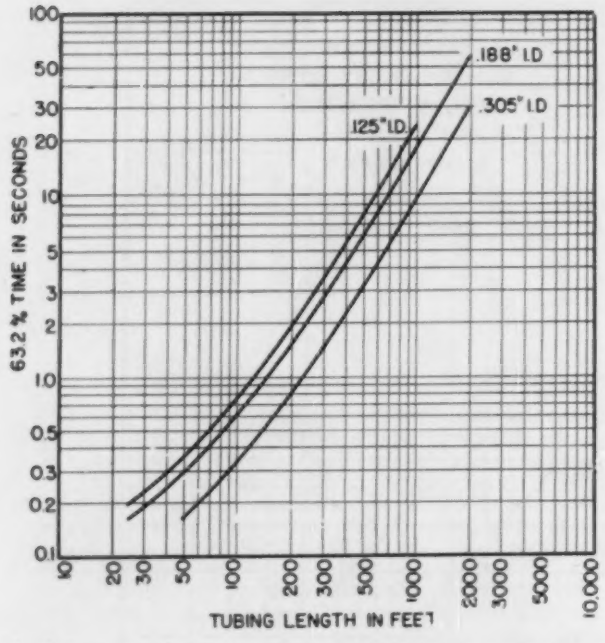

Fig. 6. Step upset, 63.2% time constants, infinite capacity source, bellows termination, .125" I.D. tubing, .188" I.D. tubing, .305" I.D. tubing, 3-15 lb./in.^{2} upset.

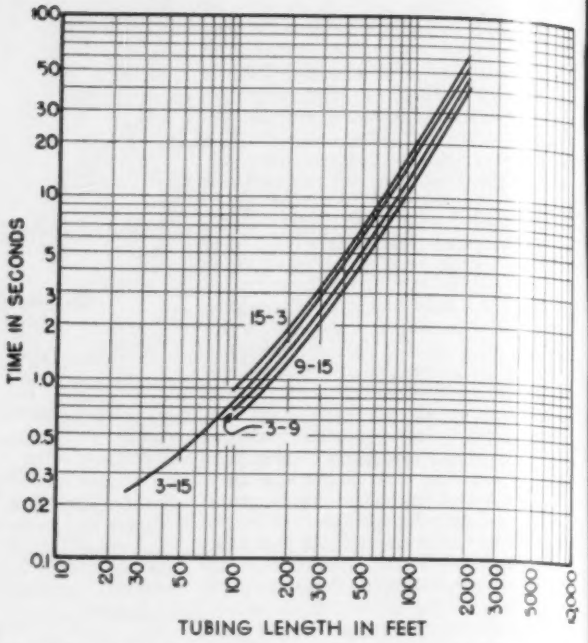

Fig. 9. Step upset on 63.2% time constants, effect of size and direction of upset, infinite capacity source, bellows termination, .188" I.D. tubing.

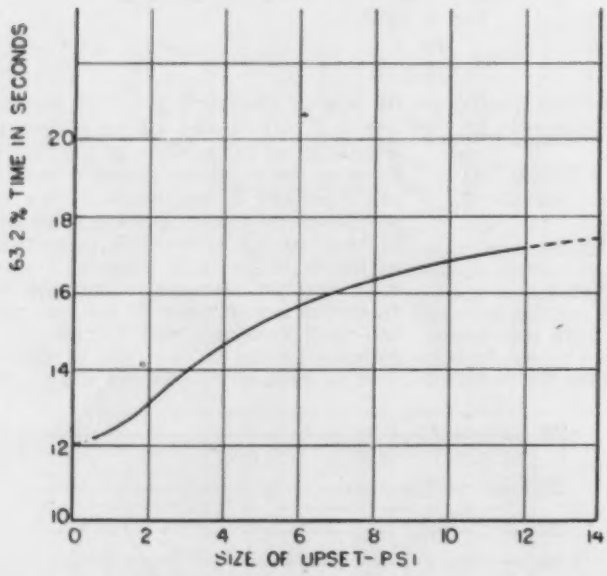

Fig. 10. Step upset, effect of size of upset on 63.2% time constant with midpoint at 9 lbs./in.^{2}, infinite capacity source, bellows termination, .188" I.D. tubing, 1000 ft. length.

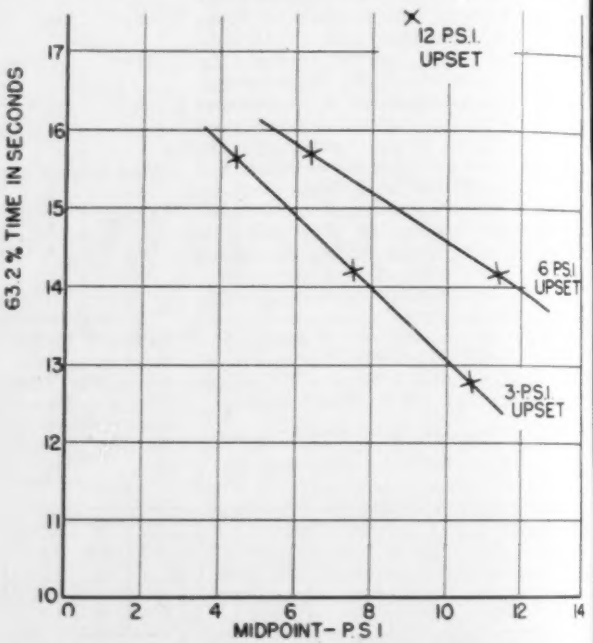

Fig. 11. Step upset, effect of various midpoints on 63.2% time constant, infinite capacity source, bellows termination, .188" I.D. tubing, 1000 ft. length.

fact that practically the only time that step upsets are introduced into industrial processes is when the control point is suddenly changed, there is considerable question as to the value of step upset data in the determination of lags in transmission systems.

Constant Rate Disturbances

As shown in Fig. 12 and described in Appendix A, the input pressure to the tubing was varied at a constant rate and the difference between input and output pressures was recorded as well as the input pressure. This type of upset comes very close to duplicating the conditions found in the great majority of industrial processes and the only nonlinearities (such as caused by transition from turbulent to laminar flow) that will enter into the measurements are existant in industrial processes and therefore should be measured. This apparently is not the case in step upset measurements.

In these constant rate disturbance tests the time lag was measured as the actual time the output lagged behind the input pressure—see Fig. 13. The data on these lags is far less involved and far less dependent upon variables than is the data for step upsets. The information from the approximately 100 runs taken in this series show conclusively that any given length and diameter of tubing will have the same time lag regardless of the rate or direction of upset. Fig. 13 shows characteristic curves obtained in these tests. It can be seen that after an initial transient the output pressure rises at exactly the same rate as the input pressure does (differential is constant), but lagging behind in time. When the rate of change was higher the pressure differential between the input and output was proportionately greater so that the actual time lags were identical. Measurements were made by connecting a differential pressure Recorder to the two ends of the tubing,—knowing the rate of rise, based on the cam and cam motor, and having measured the differential pressure, the actual time lag can be calculated easily. Fig. 14 gives the lags for both

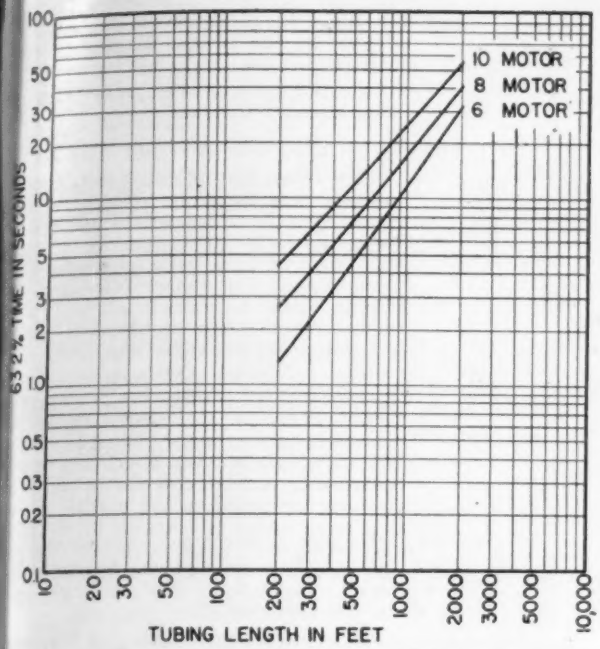

Fig. 7. Step upset on 63.2% time constant, infinite capacity source. Foxboro Stabilflo valve, motor termination, .305" I.D. tubing, 3-15 lbs./in.^{2} upset.

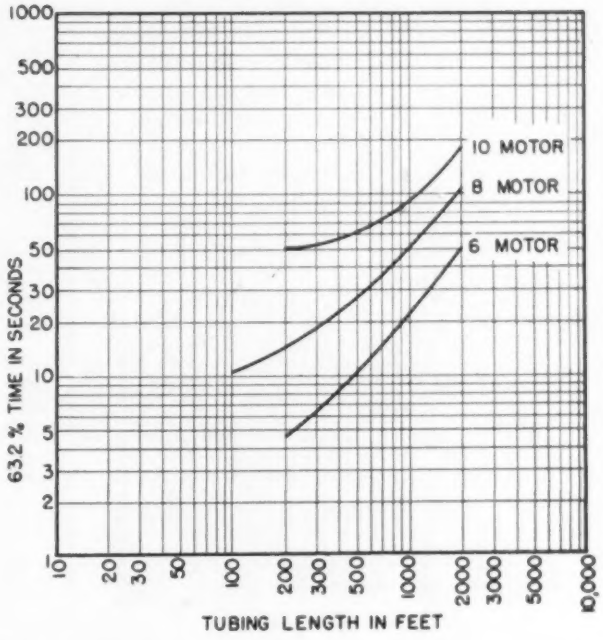

Fig. 8. Step upset on 63.2% time constant, infinite capacity source. Foxboro Stabilflo valve, motor termination, .188" I.D. tubing, 3-15 lbs./in.^{2} upset.

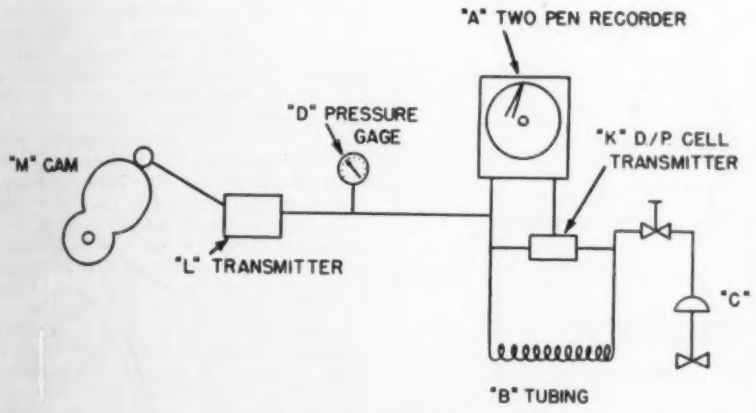

Fig. 12. Constant rate apparatus.

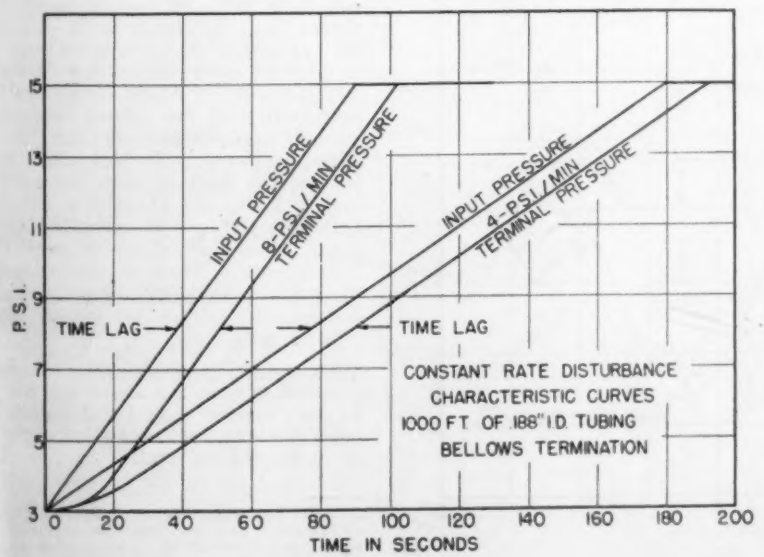

Fig. 13.

.188 I. D. and .305 I. D. tubing. The curves can be seen to be straight lines on log-log paper and therefore differ from the curves obtained on the step upset series (see Fig. 6). The difference, however, is found at short lengths and therefore short times, and could be the result of the recording equipment used in the step upset tests having a time constant of a few tenths of a second. Since the important measurement in a constant rate test was the pressure drop across the tubing (and this is constant throughout a run) there will be no such effect by time constants of the recording equipment.

It is interesting to note in Fig. 10 that the limiting 63.2% time lag value as the size of upset of reduced to zero is the same value (12 seconds) as found in the constant rate disturbance tests for the 1000 ft. length of .188 I.D. tubing.

Sinusoidal Disturbance (Frequency Response)

Fig. 15 shows the apparatus used in these tests. A sinusoidally varied air pressure was introduced into the input and the two-pen Recorder was connected to the input and output ends of the tubing (see Appendix A).

A typical test record is shown in Fig. 16 where it can be seen that the signal at the end of the transmission line is sinusoidal and has the same frequency as that imposed on the line. The terminal amplitude is less than the input and the terminal signal is lagging behind the input one. Fig. 17 gives the phase lag (lag in angular degrees—one cycle equals 360°) versus the lengths for .188 I.D. tubing at several frequencies (given in cycles per hour) and Fig. 18 gives the amplitude reduction (expressed as the ratio of terminal to input pressures) versus length for .188 I.D. tubing at several frequencies. For the convenience of the frequency analysis (servo-mechanism) group this data has been replotted as phase lag versus

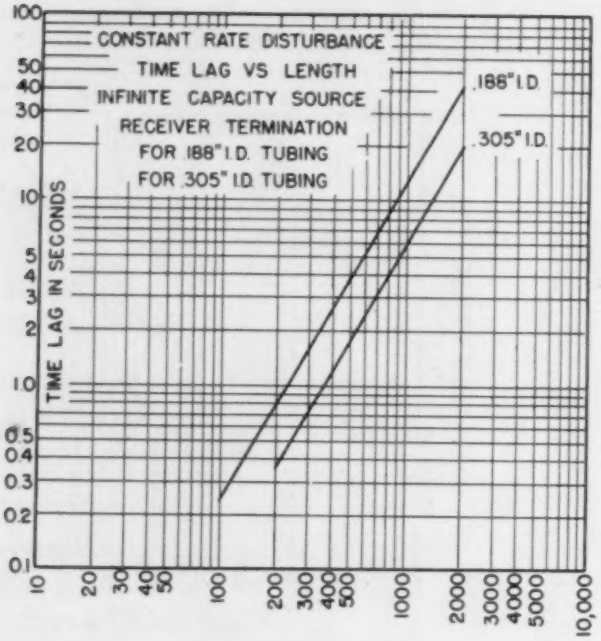

Fig. 14.

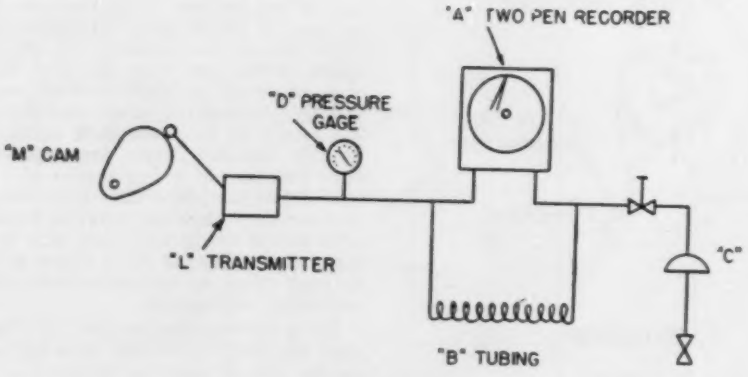

Fig. 15. Frequency response apparatus.

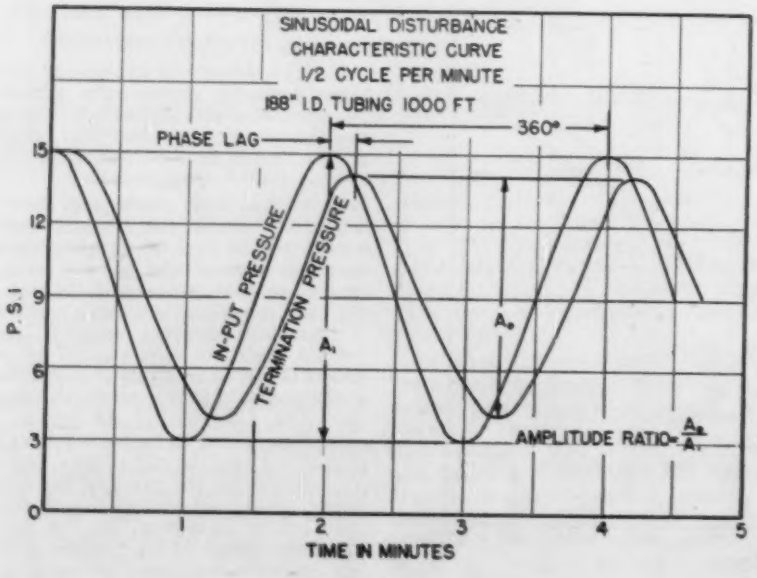

Fig. 16.

frequency for several lengths of tubing in Fig. 19 and amplitude ratio versus frequency for several lengths of tubing in Fig. 20.

No attempt has been made to carry this analysis further.

Actual Transmission Systems

The above data is usable only in theoretical considerations of lags in complete systems. Although no attempt is being made in this paper to evaluate the effect of these lags on control systems the effect on remote recording was tested using a representative Transmitter-Receiver system (Foxboro M/42 Pneumatic Transmitter and Receiver).

Fig. 21 shows a schematic of the Foxboro M/42 Pneumatic Transmitter where it can be seen that a flapper is moved toward or away from a nozzle by the difference between the motion of the measuring element and the motion of a bellows connected to the output of the air relay which is operated by the nozzle pressure. The output of this air relay also goes through the transmission line to the bellows that moves the pen in the receiving Recorder.

In obtaining the data for the constant rate upset section above a standard M/42 Pneumatic Transmitter was used in which a motor driven cam was substituted for the element and a sensitive Pressure Recorder was connected to the nozzle system in order to record accurately the amount that the output pressure lagged behind the cam. All data used in the constant rate upset section above was within a zone in which this nozzle pressure showed that the air relay output never lagged behind the cam position more than .2% of the total 12 psi swing. By checking over the nozzle pressure records on the constant rate tests it was possible to plot the relation between rate of change and length of tubing within which the instrument error was less than .2 of 1%. Fig. 22 is such a plot for .188 I. D. tubing which is most commonly used in transmission systems. It can be seen that with 2000 feet of .188 I. D. tubing the instrument error will be less than 0.2% with rates slower than full scale in ½ a minute. Since the time lag with this tubing alone is approximately 40 seconds (see Fig. 14) the additional lag due to this .2% error is insignificant (approximately .05 seconds)*. With 100 feet of tubing rates slower than full scale in ⅛ of a minute are within the 0.2% error zone. The instrument error lag of approximately .015 seconds* is again insignificant as compared with the tubing time lag of approximately .3 seconds (see Fig. 14). These values are for operation at 15 psi and the limiting rates are approximately twice the above (¼ min. and 1/16 min.) if one is operating around 9 psi. Since the volume of valve relay (valvactor) bellows is approximately the same as that of pneumatic receiver bellows, the above discussion applies equally well.

Since industrial processes commonly are slower than the above rates it can be seen that in long transmission systems the lags are due almost exclusively to the tubing itself.

*This .015 second figure is derived from the stated error and the rate. The maximum rate covers full scale in ¼ minute, that is 100% corresponds to 7½ seconds. The time for 0.2% scale is then .002 x 7½ or .015 seconds.

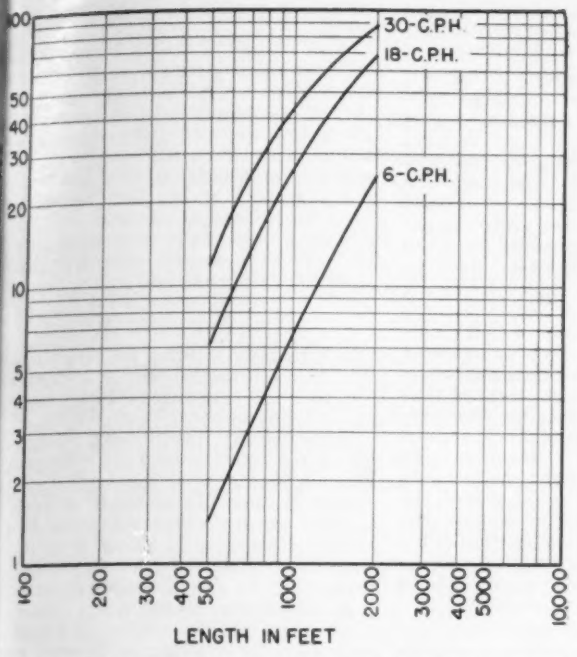

Fig. 17. Sinusoidal disturbance, phase lag vs. length, .188" I.D. tubing.

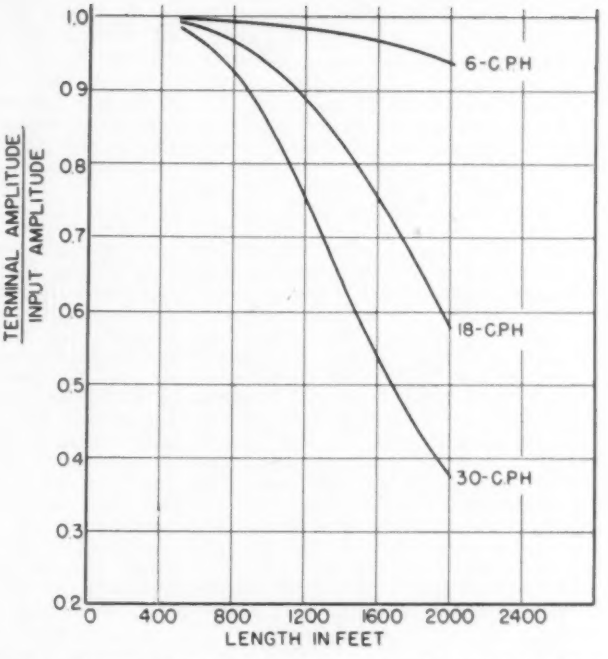

Fig. 18. Sinusoidal disturbance attenuation vs. length, .188" I.D. tubing.

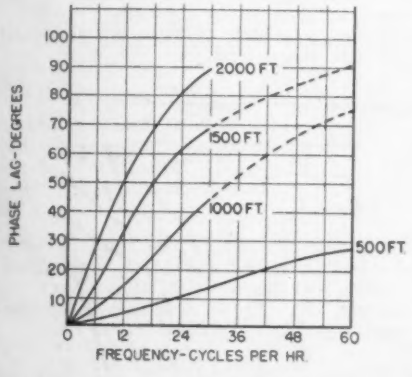

Fig. 19. Sinusoidal disturbance phase lag vs. frequency, .188" I.D. tubing.

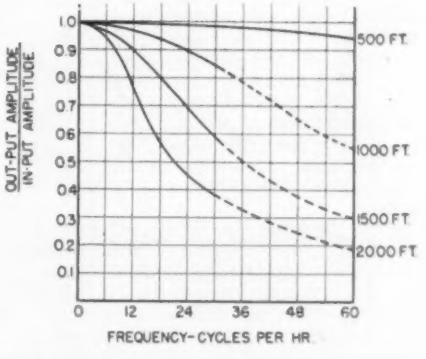

Fig. 20. Sinusoidal disturbance attenuation vs. frequency, .188" I.D. tubing.

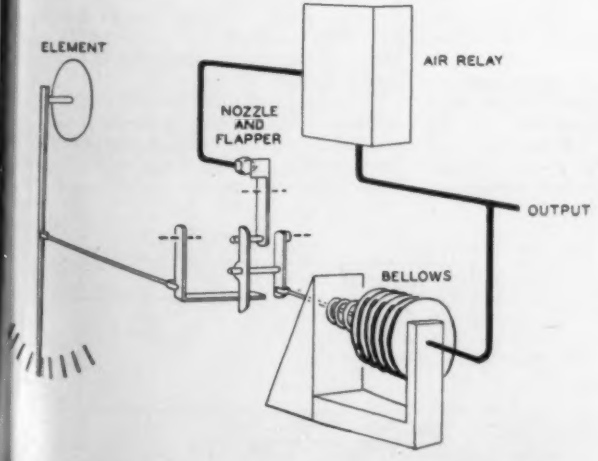

Fig. 21. Schematic drawing of Foxboro M-42 Transmitter.

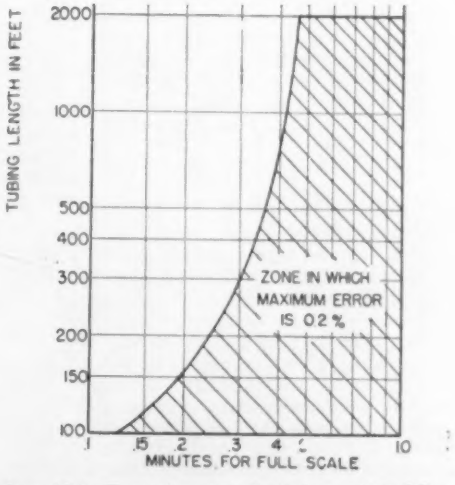

Fig. 22. Foxboro M-42 Transmitter rate limitations, .188" I.D. tubing.

Summary

The above data on lags in pneumatic transmission lines has been presented as plain data and nothing more—no attempt has been made to determine the effect of these lags on control systems. There is considerable danger in attempting superficially to apply this data to any particular process control problem since the effect of changing the lag in any one component of a system is not obvious. An example of this situation can be found in the installation of a valvactor to speed up the operation of a valve—many of the readers can testify that doing this one time improved the control and at another time made it much poorer. It has been shown analytically that the presence of hysteresis or friction is always harmful to a control system while the addition of a lag not involving a discontinuity may help or harm the stability of the system depending upon the conditions.

Several observations were made during the tests that should influence further investigation of lags:

1) Long tubing lengths do not behave as single capacity systems and therefore the 63.2% time must be used with caution.

2) The step upset method of determining the characteristics of tubing lines is of doubtful value because of the dependence of the time constants on the direction, magnitude, and midpoint of the upset.

3) The use of the constant rate disturbance method seems to be more advisable since the time lags so determined are independent of rate, direction or average pressure of the disturbance; and even more advisable since this type of disturbance more closely approximates actual conditions of use.

4) Constant rate disturbances can be used to determine the limitations of the instruments in the system while step upsets can not.

5) A certain amount of frequency analysis (sinusoidal disturbance) data has been taken. This shows the conventional pattern of decrease of amplitude and increase of phase lag at the termination as the frequency of disturbance increases. This data is presented primarily for the benefit of the considerable group accustomed to the use of this type of servo-mechanism analysis technique. It is beyond the scope of this paper to explain the interpretation of this data to those not familiar with this type of analysis.

The advantage of constant rate over step upset disturbances for lag measurements has been demonstrated only for lags occurring in tubing, but there is some reason to believe that the situation may also hold for other process lags found in industry. This has yet to be shown.

APPENDIX A

Apparatus

Fig. 1 shows the arrangement used for the step upset tests. The air pressure in tank (F) (approximately 8 cubic feet) was maintained constant (within less than 1/10 psi) by the off-on controller (G) and ½" valve (H)) to 100 psi air line or to an exhaust. (Thus providing an essentially infinite capacity supply. A special two-pen Recorder (A) recorded the pressure at both ends of the tubing (B) as the air flowed from the tank. The Recorder had one pen on the back and one on the front of special vellum charts—thus giving identical time and pressure calibrations.

The procedure for running a test was as follows (assuming a 3 to 15 psi step was to be used). With manual switch (E) closed the tank pressure was set at 15 psi and held there by the controller. Valves (I) were opened and the tubing conditioned to 3 psi by regulator (J). Valves (I) were closed and the pens on the Recorder observed for a period of time to be sure there were no leaks and that tubing was completely equalized. The chart drive motor was started and manual air switch (E) thrown producing the record. In order to limit the data to the characteristics of the tubing itself it was essential that the system have a negligible termination volume as well as an infinite source. A standard pneumatic receiver was used for the termination pressure record since careful tests showed that the bellows had a negligible volume—no measureable difference was found between it and a much smaller volume pressure recorder helical element, even with short lengths of tubing.

Fig. 12 shows the constant rate test equipment. The constant rate pressure change was produced by a cam (M) moving the arm of a position transmitter (L). The same two-pen Recorder (A) was used, with one pen recording the pressure at the input to the tubing (B), but the other pen was connected to differential pressure element (K), (a Foxboro D/P Cell was used because of its rapid response) connected across the tubing, giving a direct reading of the pressure differential and avoiding the necessity of taking the difference between two curves to obtain the value. (Knowing the rate of pressure change from the cam, the time lag is readily calculated from the pressure differential.) In addition, the Differential Pressure Instrument had a narrower range and therefore enabled greater accuracy in the reading. The connections to the Differential Pressure element were reversed by a 4-way valve when the upset changed in direction.

Fig. 15 shows the apparatus used to obtain frequency response data. A sine wave variation was generated by the same cam—transmitter arrangement as above. The same two-pen Recorder (A) was connected to input and output of the tubing as in the step upset arrangement.

In all cases the tubing was in 50 and 100 foot lengths connected by compression fittings and coiled in approximately 18-inch diameter coils. All connecting tubing was kept as short as possible to minimize its effect. All data on constant rate and sinusoidal upsets was limited to a zone well within the limitation of the control head being used and therefore the source can be considered as having infinite capacity (see text under constant rate changes).

APPENDIX B

Subject: Determining the Dynamic Characteristics of a Pneumatic Transmission Line from Experimental Response Data.

Since the lag introduced by long tubing is not logarithmic (single capacity) type, a single time constant does not define the lag. However, it is possible to give an analytical definition of the observed response in terms of an initial time delay followed by a curve having three or more separate time constants.

A pneumatic transmission line consists of an infinite number of distributed pneumatic impedances. In some cases the line may be described by a lumped —constant network consisting of a discrete number of passive elements. This approach, where successful, has been made by considering an equivalent pneumatic line made up of ideal pneumatic resistances and capacity tanks arranged as a series lag networks. Fig. (A-1) is a sketch of such an equivalent pneumatic line.

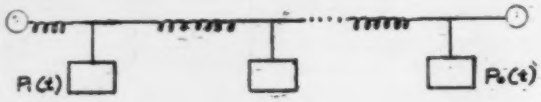

Fig. A-1.

P_i (t) is the input pressure to the line and P_o (t) is the output pressure at line's outlet. When P_i (t) is specified, P_o (t) is determined by the dynamic characteristics of the line.

Sudden change in P_i (t):

Let P_i (t) be a sudden increase in pressure of magnitude P_i.

Then

$$P_o(t) = \Delta P \left[1 + K_1 e^{-\frac{t}{T_1}} + K_2 e^{-\frac{t}{T_2}} + \cdots K_n e^{-\frac{t}{T_n}} \right] + P_i \text{ (INITIAL)}$$

where multiplying constants K_1, K_2, . . . K_n and time T_1, T_2 . . . T_n are complex functions of the pneumatic resistances and capacity tanks of the equivalent pneumatic line.

It has been found experimentally that a three-term series describes the response, P_o (t), of most of the pneumatic lines tested. Thus, when n = 3, the solution takes the form:

$$P_o(t) = \Delta P_i \left[1 - \frac{T_1^2 e^{-t/T_1}}{(T_1 - T_2)(T_1 - T_3)} + \frac{T_2^2 e^{-t/T_2}}{(T_1 - T_2)(T_2 - T_3)} - \frac{T_3^2 e^{-t/T_3}}{(T_1 - T_3)(T_2 - T_3)} \right] + P_i \text{ (INITIAL)}$$

$$\text{AS } P_o(t) - P_i \text{ (INITIAL)} = \Delta P_o(t)$$

$$\frac{\Delta P_o}{\Delta P_i}(t) = 1 - \frac{T_1^2 e^{-t/T_1}}{(T_1 - T_2)(T_1 - T_3)} + \frac{T_2^2 e^{-t/T_2}}{(T_1 - T_2)(T_2 - T_3)} - \frac{T_3^2 e^{-t/T_3}}{(T_1 - T_3)(T_2 - T_3)}$$

A plot of $\frac{P_0}{P_i}$ versus time appears as in

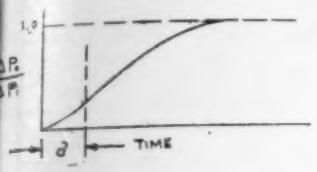

Fig. A-2.

After a sufficient time internal, a, the fects of all the exponentials but a sin- e predominant one will have disap- eared. That is, the exponentials hav- g the smaller time constants have de- yed to such an extent that the system described by a single exponential. hus with an infinitesimal error,

$$\frac{\Delta P_0}{\Delta P_i}(t) = 1 - \frac{T_1^2 e^{-t/T_1}}{(T_1 - T_2)(T_1 - T_3)}, \quad t > a$$

$$\text{or } 1 - \frac{\Delta P_0}{\Delta P_i}(t) = \frac{T_1^2 e^{-t/T_1}}{(T_1 - T_2)(T_1 - T_3)}, \quad t > a$$

king the natural logarithm of (3) hus if

$$\ln\left[1 - \frac{\Delta P_0}{\Delta P_i}(t)\right] = \frac{t}{T_1} + \ln\left[\frac{T_1^2}{(T_1 - T_2)(T_1 - T_3)}\right]$$

$$1 - \frac{\Delta P_0}{\Delta P_i}$$

plotted on logarithmic co-ordinates gainst time on linear co-ordinates, as Figs. (A-3), (A-4) and (A-5), the ope of the straight line portion of

$$\ln\left[1 - \frac{\Delta P_0}{\Delta P_i}(t)\right] \text{ is } \frac{-1}{T_1}, \text{ since } \ln\left[\frac{T^2}{(T_1 - T_2)(T_1 - T_3)}\right]$$

a constant term which may be dis- garded. T_2 is found by subtracting

$$\ln\left[1 - \frac{\Delta P_0}{\Delta P_i}(t)\right]$$

from $\frac{-1}{T_1}$ and laying out the difference on the co-ordinates initially used. That is:

Thus the slope of the straight line portion of the curve obtained is $-\frac{1}{T_2}$

This procedure is continued until all effective time constants are determined, that is, until a final subtraction produces a straight line plot of the difference with respect to time.

$$\ln\left\{\frac{T_1^2 e^{-t/T_1}}{(T_1 - T_2)(T_1 - T_3)} - \left[1 - \frac{\Delta P_0}{\Delta P_i}(t)\right]\right\} = \frac{-t}{T_2} - \ln\left[\frac{T_2^2}{(T_1 - T_2)(T_2 - T_3)}\right]$$

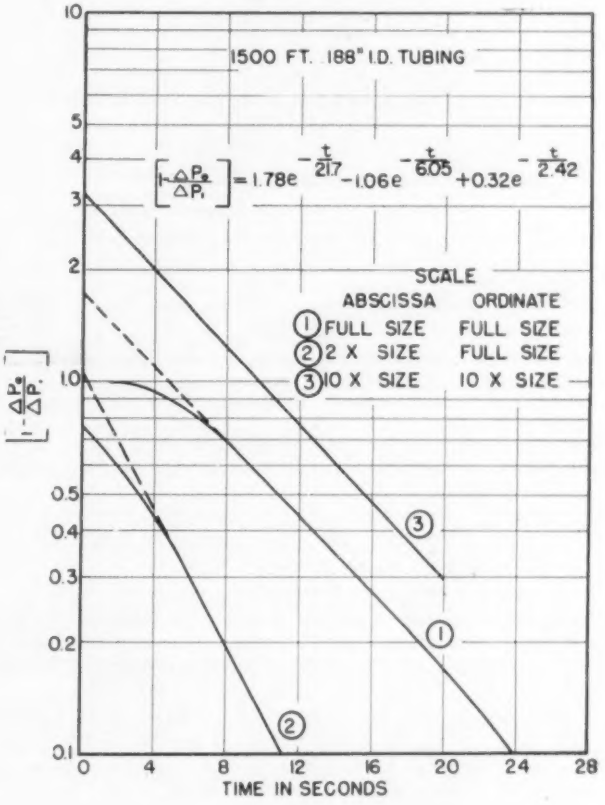
1500 FT. .188" I.D. TUBING
[1 - ΔP₀/ΔPᵢ] = 1.78e^(-t/21.7) - 1.06e^(-t/6.05) + 0.32e^(-t/2.42)
SCALE
ABSCISSA ORDINATE
① FULL SIZE FULL SIZE
② 2 X SIZE FULL SIZE
③ 10 X SIZE 10 X SIZE
1 - ΔP₀/ΔPᵢ
TIME IN SECONDS

Fig. A-4.

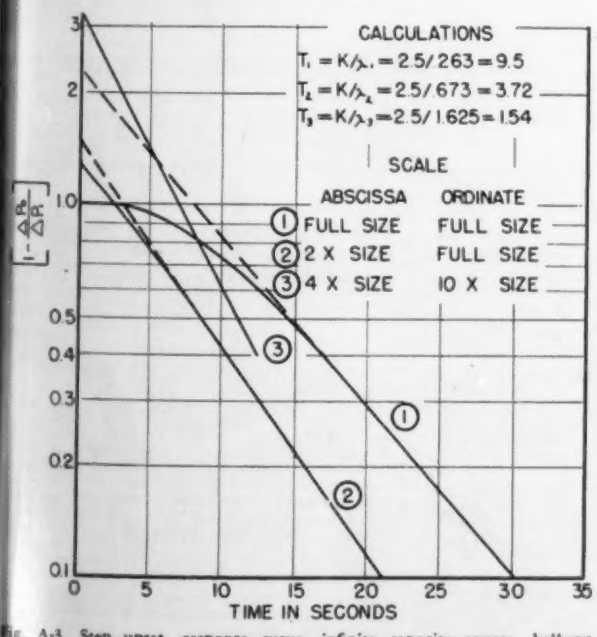
CALCULATIONS
T₁ = K/λ₁ = 2.5/.263 = 9.5
T₂ = K/λ₂ = 2.5/.673 = 3.72
T₃ = K/λ₃ = 2.5/1.625 = 1.54
SCALE
ABSCISSA ORDINATE
① FULL SIZE FULL SIZE
② 2 X SIZE FULL SIZE
③ 4 X SIZE 10 X SIZE
TIME IN SECONDS

Fig. A-3. Step upset, response curve, infinite capacity source, bellows rmination, .188" I.D. tubing, 1000 ft. length.

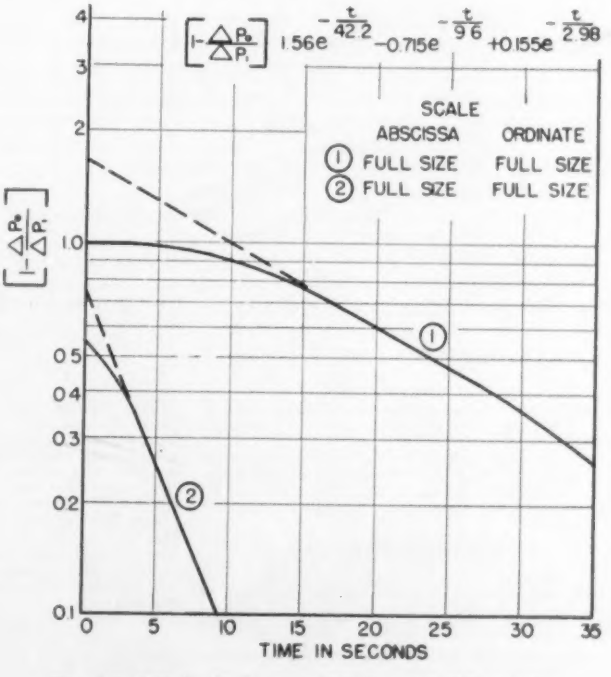

Fig. A-5. 3-15 lbs./in.² upset, 2000 ft., 188" I.D. tubing.

SECTION SECRETARIES AND MEETING DATA

	Telephone	*Date*	*Dinner*	*Meeting*
Akron: Fred Appel, 932 Columbia Ct., Barberton, Ohio.		4 Tues.	X	8:00
Aruba: A. S. MacNutt, c/o Lago Oil & Transport Co., Ltd., Aruba, N.W.I.		1 Tues.	X	7:15
Atlanta: H. Kockritz, Fischer & Porter Co., 84 Peachtree St., Atlanta, Ga.		4 Mon.	X	7:45
Baltimore: Felix Cox, Bethlehem Steel Co., Sparrows Point, Md.		2 Fri.		
Baton Rouge: James H. Simpson, 3647 Gladiola, Baton Rouge, La.				
Boston: C. J. Nazzaro, 456 Central Avenue, Milton 87, Mass.		Last Wed.	6:00	7:00
California: D. D. Taylor, 234 E. Colorado, Pasadena 1, Calif.		1 Tues.	6:30	
Central Illinois: H. F. Lange, 2101 W. Glen Avenue, Peoria 5, Ill.		1 Wed.	6:30	7:30
Central Indiana: H. F. Coffey, 110 G Nelson Ave. Tyndall Towne, Indianapolis, Ind.		1 Tues.	X	7:30
Charleston: Albert H. Hix, 1529 B Dixie St., Charleston 1. W. Va.		1 Mon.	X	8:00
Chicago: Floyd E. Ertsman, Rm. 1420 Fisher Bldg., 343 S. Dearborn St., Chicago, Ill.		1 Mon.	6:30	8:00
Cincinnati: Smith Hickenlooper, 1147 Beverly Hills Dr., Cincinnati, Ohio.		3 Fri.	X	8:00
Cleveland: R. M. Woodside, Brown Instrument Div. of Minneapolis-Honeywell Reg. Co., 5005 Euclid Ave., Cleveland 5, Ohio.		4 Wed.	6:30	8:00
Cumberland: Clyde Babst, P. O. Box 447, Cumberland, Md.		*Tues. after 4 Mon.*	6:30	8:00
Detroit: T. S. Cawthorne, 570 Maccabees Bldg., Detroit 2, Mich.		3 Tues.		
Eastern New York: Wm. J. Claffie, Winthrop-Stearns, Inc., 33 Riverside Ave., Rensselaer, N. Y.		1 Tues.	6:30	8:00
Gulf Coast: A. E. Bunn, 2237 North Street, Beaumont, Texas.		3 Tues.		
Houston: E. E. Kleir, 2518 S. Blvd., Houston 6, Texas.		Last Mon.	X	8:00
Inyokern, China Lake, Calif.; A. G. DeBell, U.S. Naval Ordnance, Test Sta., China Lake, Calif.				
Kansas City: Lewell F. Spies, J. F. Pritchard & Co., 908 Grand Ave., Kansas City, Mo.		Last Tues.	6:30	7:30
Louisville: H. C. Scherffius, 980 Palarka Rd., Louisville, Ky.		4 Tues.	X	8:00
Montreal: F. S. McCarthy, Canadian Industries, Ltd., Box 10, Montreal, Quebec, Canada.		Last Mon.	X	8:00
New Jersey: W. D. Archibald, 605 Westminster Ave., Elizabeth 3, N. J.		1 Tues.	6:00	
New Orleans: W. H. Haney, 2927 Music Avenue, New Orleans, La.		*No Regular Date*		8:00
New York: Norman J. Cherry, Merrick, L. I., N. Y.		Last Mon.	6:30	8:00
Niagara Frontier: E. J. Hayter, 374 Huntington Ave., Buffalo, N. Y.		4 Mon.	X	8:00
North Texas: F. Zapffe, Lone Star Gas Co., 2701 Logan St., Dallas 1, Texas				
Northern Indiana: C. P. Haynes, 935 177th Place, Hammond, Indiana.		3 Wed.	6:30	7:30
Oak Ridge: John H. Clark, 138 Clayton Hall, Oakridge, Tenn.		1 Wed.	6:30	7:30
Ontario: John W. Huether, 311 Southerland Dr., Leaside, Ontario, Canada.		3 Thur.	6:45	
Philadelphia: C. W. Wood, 6908 Market St., Upper Darby, Pa.		3 Wed.	X	8:00
Pittsburgh: Miss Louise Suckfield, Gulf Research Corp., Pittsburgh 13, Pa.		4 Mon.	6:30	8:00
Presque Isle: Edwin P. Schuwerk, 445½ Halley St., L. P., Erie, Penna.		4 Tues.	X	8:00
Richland: R. S. Hammond, 402 Abbott, Richland, Washington.		2 Wed.	X	7:30
Rochester: R. C. Swartz, Jr., 1201 Granite Bldg., Rochester 4, New York.		4 Tues.	X	8:00
St. Louis: W. G. Lee, 4710 Delor St., St. Louis 16, Mo.		1 Wed.	X	8:00
Sarnia: Mr. Fred T. Yarke, 140 St. Clair St., Point Edward, Ontario, Canada.		2 Fri.	X	
South Bend: Sam M. Rouse, 436 Moccasin Ave., Buchanan, Mich.		1 Thur.	6:30	7:30
South Michigan: Homer Kuiper, 2517 Hillsdale, Kalamazoo, Mich.		2 Wed.	6:30	8:00
South Texas: H. C. Givens, La Gloria Corp., P. O. 637 Falfurrias, Texas.		1 Tues.	X	7:30
Tennessee: N. M. Taylor, 16 Edgewood, Kingsport, Tenn.		*No Definite Night*	7:00	8:00
Tulsa: C. R. Horton, 8211 E. 7th, Tulsa, Oklahoma.		1 Mon.	X	7:30
Twin Cities: Ray Hooper, International Div. Minneapolis-Honeywell Reg. Co., 2753 Fourth Ave., Minneapolis 8, Minn.		4 Tues.	6:30	
Washington: Edwin G. Brown, c/o American Instrument Co., 8010-20 Georgia Avenue, Silver Spring, Md.		3 Mon.	X	7:30
Wayne County: Robert Karr, 2455 Biddle Avenue, Wyandotte, Michigan.		3 Mon.	6:30	8:00

(Continued from page 617)

usually interesting to the members. As many as five pressure channels may be recorded synchronously.

To date this equipment has been used only on animals. The next step is to use it on human beings. It was suggested that Ollie Boutrous be the first to be experimented on but he declined the honor.

The tentative schedule of meetings for joint cooperation of St. Louis, Tulsa and Kansas City Sections was approved by the membership. The first meeting will be held the first Monday of the month, in Tulsa. The next meeting will be in Kansas City the first Tuesday following the first Monday of the month. The next will be held in St. Louis the first Wednesday following the first Monday in the month.

—W. A. Reichow, Corr.

MONTREAL

The Foxboro plant at Ville LaSalle was the locale for the final meeting of the season on May 30th. This meeting, the only non-technical one of the year, took the form of a business meeting and social evening. Reports on activities and achievements were provided by the various committee chairmen.

Bob Brown, the retiring president, reviewed the history of the section since its original formation as the Instrument Society of Montreal in 1947. The present membership stands at 78, an indication of the rapid progress of the section.

The social portion of the evening was excellently arranged by John Hilden and ample food, refreshments, and music provided for the large attendance. Meetings will resume in September.

—G. A. Rice, Corr.

NEW JERSEY

The regular meeting was held May 3rd at the Essex House, Newark, N. J. Mr. H. Zeibolz, Vice President, Regulator Company, gave a very interesting talk on "Hydraulic Control Circuits and their Applications to the Control of Industrial Processes". His discussion, illustrated with slides, showed the similarity in principle between a number of hydraulic circuits and the more widely known pneumatic controllers. His talk brought out the advantages of the hydraulic systems where high speed of controller are required.

Following the discussion of Mr. Zeibolz's talk, Mr. Herbert Close, Section President, read a summary of formal reports prepared by the officers and committee chairman on their activities for the past year.

—W. A. Hagerbaumer, Corr.

OAK RIDGE

Continuity of interest in the field of Instrumentation and in the affairs of the Oak Ridge Section was again demonstrated by members and guests at the regular meeting on May 4, 1949. We had a good attendance at the Dinner preceding the regular business meeting and by the end of the dinner period most of our members were there and had brought many guests with them.

Our May 4th meeting opened with the selection of the winner of the ISA pin, Mr. E. W. Burdette of the Oak Ridge National Laboratories. It was then announced by our president, W. J. Kaniniak, that the General Electric Co. desired to exhibit a group of instruments here on June 14th. We hope to arrange the floor space for this showing. This will be a special meeting since we have completed arrangements for the regular meeting.

The program Committee has secured the following men as guest speakers for future programs: Mr. Jerry James of the Oak Ridge National Laboratory for the August date, Mr. Dyer of the C. P. Clare Relay Co. for October and Mr. Tatnall of the Baldwin Locomotive Works for the November meeting.

Our speakers of the evening were Messrs G. L. Hommell and B. A. Kleinhofer of the L. and N. Co. Their general topic was "Low Level Measurements". They discussed the L. and N. low level amplifier for Nicrovolt range instruments.

—JOHN H. CLARK, Sec'y.

PHILADELPHIA

Our May 18th meeting attracted 118 persons to hear Mr. Dahl of Hammel-Dahl Co., discuss Valve Design and Application. Mr. Dahl discussed the manufacturer's problems in applying valves under conflicting requirements. A lively question period showed wide interest in this important subject.

—W. E. HARRISON, Corr.

PITTSBURGH

About 100 members and guests at the May meeting heard Mr. Otto J. Leone, Manager of Industrial Sales of Trion, Inc., speak on "Instruments and Controls for Blast Furnaces".

The main control problem according to Mr. Leone is one of materials handling, which does not allow very much control in the furnace. There are three items which determine operating procedure: 1. Furnace factors, such as construction materials and dimension; 2. Burden factors, such as physical and chemical nature of charge and method of charging; 3. Air and gas factors, such as quantity, pressure and composition. Most control equipment is applied to the air and gas factors, while the burden factors can be indirectly controlled through the air and gas.

The instrumentation controls combustion processes in the stoves and furnace. The variables which are controlled include the hot blast temperature, flow, humidity and quantity. Air weight is usually measured at the blower section and controlled by changing blower speed. Air temperature is controlled by combustion in the stove and by mixing hot and cold blasts. The humidity is measured either by wet and dry bulb thermometers, or by a dew point element, but the gas sample should be temperature and pressure controlled. Steam is injected into the air blast to control the humidity. The level of charge at the top of the furnace is measured by a motor operated displacement type element.

—M. M. FROMM, Corr.

PRESQUE ISLE

A "Ladies Night" meeting was held at the General Electric Community Center on May 24. At this time Mr. D. M. Alstadt, Research Engineer of the Lord Manufacturing Co., Erie, Pa. presented a very interesting talk entitled "The Power of the Atom". This section anticipates sponsoring an "Instrument Training Course" to take place at the Behrend Center Extension of Pennsylvania State College. This class is to begin in the Fall. Anyone desiring further information can contact Mr. Ferguson, registrar of Pennsylvania State Extension at Behrend Center or any of the Society members. We are very pleased to announce that the Society has selected two most competent instructors for this course, Dr. Croup, of the Hammermill Paper Co. and Mr. R. Marshall of the Pennsylvania Electric Co.

—H. F. RONDEAU, Corr.

WASHINGTON

The May 16th meeting was held in the Pepco Building on Monday, May 16, 1949, and was well attended. Mr. W. D. MacGeorge, Director of Research of the Automatic Temperature Control Co., Philadelphia, Penna., delivered a lecture on the Atcotran System of Measurement. A rather complete set of demonstration equipment was employed to illustrate the various principles involved in the use of the system. After the completion of the demonstration and the question period a 40 minute surprise motion picture film was shown. It dealt with the building of the 200 in. reflecting telescope and was unusually well done. It may be obtained by requesting the loan of "The Story of Palomar" from the Publicity Department of the California Institute of Technology. On the twenty-third of May the local Section was taken on a conducted tour through the Federal Bureau of Investigation.

—RAYMOND E. MILLER, Corr.

WYANDOTTE

The May meeting was held at the Wabeck Tea Room. All committee members met early and after a general discussion and talk by President Bob Wright the several committees met separately and made plans for the coming year.

The program was sponsored by the Swartwout Co. Mr. Ken Swartwout gave a most instructive talk on automatic control. At first a simple float control was shown operating an on and off device and the accompanying fluctuating levels were explained. Then a proportional bellows was added and the improvement was noted and the limitations explained. Then a reset mechanism was added and the adjustments made for the best control possible all factors considered. The slides and descriptions in this demonstration were very good and helped us to understand a type of control somewhat different from those with which we are familiar.

—JOHN MACPHERSON, Corr.

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WHEN: Fourth Annual Conference and Exhibit of the Instrument Society of America, September 12-16, 1949.

WHERE: Municipal Auditorium, St. Louis, Mo.

Seeking a Position in Instrumentation? Registration forms and further instructions may be obtained from the Society Office. Pre-registration by applicants is advisable, as records will be made available to prospective employers before the week of the Conference and Exhibit.

Do You Need An Instrument Man? Companies or institutions seeking instrument men are requested to file notice of open positions prior to the week of the Conference and Exhibit so that qualified applicants may be selected for interview.

Interviews Arranged. Representatives of employers and applicants attending the Conference are urged to report to the office of the EMPLOYMENT REGISTER immediately upon arrival so that interviews may be arranged.

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Manufacturers' New Literature

In this department we report new literature pertaining to Instrumentation, received from the manufacturers. We urge readers to request ONLY those bulletins which will be of value to them. Use the Postage-free Order Card on Page 631.

R-336 FLOW METERS. 12-page bulletin contains reprints of ten advertisements from engineering journals explaining the essential features and operation of maker's "Ring Balance Meters."—Hagan Corp., Hagan Bldg., Pittsburgh, Pa.

R-337 "EBERBACH ANNOUNCER." 16-page No. 49-3-34 issue of this house organ presents article titled "The Evolution of Modern Glass." Contains description and illustrations of microscopes, vacuum pressure regulators, and other instruments.—Eberbach & Son Co., Ann Arbor, Mich.

R-338 AIRCRAFT TEST EQUIPMENT. 8-page bulletin describes and illustrates various types of aircraft test equipment. Included are: hydraulic component and pump test stand, portable hydraulic test stand, fuel flow pump test stand, etc.—Sprague Engineering & Sales, 1144 West 135th Street, Gardena, Calif.

R-339 ELECTRIC HEATING UNITS AND CONTROLS. 22-page Bulletin 103 illustrates and describes maker's "Electro-Therm" tubular pipe-fitting and flange-mount industrial-type heaters, and appropriate controls. Gives detailed specifications for wide variety of applications.—Electro-Therm Inc., Silver Springs, Md.

R-340 INTERVAL TIMERS. 10-page bulletin describes and illustrates maker's "Gralab" automatic switching interval timers designed for laboratory tests, process engineering, inspection tests, instrument calibration, etc.—Dimco-Gray Co., 207 E. Sixth St., Dayton 2, Ohio.

R-341 "THE GENERAL RADIO EXPERIMENTER." 8-page Vol. 23, No. 11 issue of this house organ presents article titled: "Variac Motor Speed Controls."—General Radio Co., 275 Massachusetts Ave., Cambridge 39, Mass.

R-342 PLASTIC FABRICATION. 6-page folder describes and illustrates maker's plastic fabricating machine models, showing designs and products obtainable.—Plastic Machine Div., Taber Instrument Corp., 111 Goundry St., North Tanawanda, N. Y.

R-343 OPTICAL EQUIPMENT. 4-page bulletin describes and illustrates maker's optical equipment including research microscopes, routine microscopes, etc. Includes information on nuclear particle emulsion, and photomicrographic equipment for recording.—Heinicke Instrument Corp., 315 Alexander St., Rochester 4, N. Y.

R-344 HIGH-VOLTAGE RELAYS. 4-page Data Section 1500 presents discussion of high voltage relays, describes several models of maker's relays, gives ordering information.—Struthers-Dunn, Inc., 150 N. 13th St., Philadelphia 7, Penna.

R-345 THICKNESS MEASURER. 4-page Bulletin 3700 illustrates and describes maker's "Reflectogage," a portable ultrasonic instrument for visual indication of thickness of metals and other materials from one side of material only. General operating instructions, etc., included.—Sperry Products, Inc., Danbury, Conn.

R-346 HEAT AND AIRFLOW DETERMINATION. 34-page booklet describes and illustrates maker's aircraft test instruments, including: hot gas thermocouples, temperature survey rakes, etc. Also described are: embedded bayonet thermocouples, liquid and gas immersion thermocouples, thermocouple harness, wire, insulation, etc.—Rever Corp. of America, Wallingford, Conn.

R-347 "THE ROMANCE OF ELECTRICITY." 58-page booklet presents the story of electricity in nineteen chapters.—General Electric Co., Schenectady, N. Y.

R-348 ELECTROSTATIC SAMPLER. 4-page bulletin describes and illustrates maker's electrostatic sampler for quantitative sampling of airborne particles. Applications, advantages, operation, etc. are discussed.—Mine Safety Appliances Co., Braddock, Thomas and Meade Streets, Pittsburgh 8, Penna.

R-349 COUNTING UNIT. 2-page bulletin describes and illustrates maker's "Model 700" decimal electronic counting unit which directly indicates counts, thus eliminating interpolation. Features, applications, etc. discussed.—Berkeley Scientific Co., Sixth and Nevin Ave., Richmond, Calif.

R-350 HYDRAULIC REGULATORS. 2-page bulletin and explanatory drawing C-100 describes and illustrates maker's automatic hydraulic regulators for control of pressure, volume flow, ratio, mixture, combustion, draft.—Shallcross Controls, Inc., 2217-2221 No. 31st St., Milwaukee 8, Wis.

R-351 RESISTOR DATA. 22-page bulletin R-3 lists 47 of maker's standard "Akra-Ohm"

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cision resistor types, including types designed "JAN R-93." Booklet contains mounting ts, data on time versus temperature factors, perature coefficient, etc.—Shallcross Mfg. Co., lingdale, Penna.

R-352 TIMING MOTORS AND DEVICES. ge Catalog No. 321 describes and illustrates r's line of syncronous timing motors, chart s, timing devices, clock movements. Also des line of direct current timers and motors, tery charger timers, etc.—Haydon Mfg. Co. , Torrington, Conn.

R-353 "AN" DESK CHART. Desk size rt gives Army-Navy connector specifications N-C-591). Contains latest insert arrangements wn in detail for use by aircraft, radio, comnication engineers, designers, etc.—Catalog 't., Cannon Electric Dev. Co., 3209 Humlt St., Los Angeles 31, Calif.

R-354 "TRACERLOG." 12-page No. 18 ue of this house organ presents articles of eral interest to those in the field of radioiry, and describes maker's new equipment.—cerlab, Inc., 55 Oliver St., Boston 10, Mass.

R-355 GEIGER-MUELLER COUNTERS. 6-e folder gives operating instructions for ker's "Type TGC 1/1B83" and "TGC 2/1B84" iger-Mueller counters.—Tracerlab, Inc., 55 ver St., Boston 10, Mass.

R-356 STRAIN GAGES. 4-page Bulletin 279 illustrates and describes uses made of ker's "SR-4" strain gages. Gages available for ermining stresses and strains in structures, ts in service, etc. also described.—Baldwin comotive Works, Testing Equipment Dep't., iladelphia 42, Penna.

R-357 ATTENUATOR AND COMMUNIATIONS EQUIPMENT. 26-page Bulletin 4 scribes and illustrates maker's complete line of dio attenuators, fixed pads, special attenuator tworks, and other communications equipment oduced. Attenuation data included in bulletin. Shallcross Mfg. Co., Collingdale, Penna.

R-358 D.C.-A.C. CHOPPER. 2-page bulletin scribes and illustrates maker's 60-cycle s-p.d-t. ctromechanical chopper, rectifier, demodulator, square-wave generator. Specifications, conts, etc. discussed.—Stevens-Arnold Inc., 22 kins St., South Boston 27, Mass.

R-359 ROTAMETERS. 12-page Bulletin 18-C illustrates and describes maker's line of elecnic, electric, and pneumatic recording and ntrolling rotameters. Construction, operation, plication, etc. are explained.—Schutte and erting Co., 12th and Thompson Streets, Philaphia 22, Penna.

R-360 D-C. POWER SUPPLY. 2-page bulin describes and illustrates maker's regulated power supply, listing electrical characteristics, chanical specifications, appearance, etc.—Sorsen and Co., Inc. 375 Fairfield Ave., Stamford, nn.

R-361 INSULATION TESTER. 4-page ta Sheet 3001 describes and illustrates maker's odel 101 Megotron" dual voltage electronic ulation tester designed for power company use. ecifications, advantages, etc. are discussed.—W. Dice & Co., 191 River Road, Grand View-Hudson, N. Y.

R-362 CARBON DETERMINATOR. 2-e bulletin describes and illustrates maker's co No. 4500" carbon determinator for checkheats that are near specification limits, cking interplant analyses, etc. Analysis time, ration, maintenance, etc. are discussed.—Labtory Equipment Corp., St. Joseph, Mich.

R-363 COMBUSTION FURNACE. 4-page lletin describes and illustrates maker's "No. 0" 2800-degree furnace for carbon and combusn sulphur analyses; where materials are diffit to combust; where speed is desired.—Laborory Equipment Corp., St. Joseph, Mich.

R-364 RELAY TYPE GUIDE. 20-page talog G is a simplified listing of data for ection of maker's relay types. Types listed

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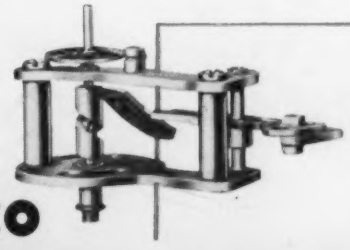

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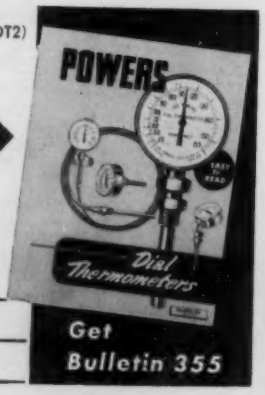

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include power relays, latch relays, sequence relays, etc. Section of catalog discusses adaptations available in standard relays.—Struthers-Dunn Inc., 150 N. 13th Street, Philadelphia, Penna.

R-365 THERMOCOUPLE INDICATOR. 2-page bulletin describes and illustrates maker's "Model A-100 Xactemp" thermocouple indicator for non-critical temperature indications. Ranges, features, etc. are discussed.—Claud S. Gordon Co., 300 S. Wallace St., Chicago 16, Ill.

R-366 LINE COUNTER. 4-page bulletin describes and illustrates maker's "Micro-Lite Counter" for rapid accurate counts of textiles, fabrics, engraving screens, etc. Uses, features, construction discussed.—Micro-Lite Co., Inc., 44 West 18 Street, New York 11, N. Y.

R-367 ETCHED-STEM THERMOMETERS. 12-page Catalog T-200 discusses facilities, workmanship, material, etc. going into maker's etched-stem thermometers. Food testing thermometers, meat and fruit testers, pocket size, A.S.T.M. and other thermometers are described. Scales, ranges, lengths, tests, immersions, divisions, etc. are listed for each type.—Ever Ready Thermometer Co., 1118 Bedford Ave., Brooklyn 5, N. Y.

R-368 INSULATION TESTER GUIDE. 8-page Bulletin No. 21-05-28 contains selection chart for choosing insulation resistance testers. Ten types of maker's "Megger" insulation testers covering range from 0.01 ohm to 10,000 megohms are discussed.—James G. Biddle Co., 1316 Arch St., Philadelphia 7, Penna.

R-369 CONTROL VALVES. 12-page bulletin describes and illustrates maker's "Domotor" control valve. Operation, specifications, flow capacity, etc. are discussed.—Annin Co., Los Angeles, Calif.

R-370 ELECTRONIC TEST EQUIPMENT. 52-page catalog illustrates and describes various types and models of electronic test equipment and quartz and germanium crystals. Includes descriptions of oscilloscopes, binary scalers, tube analyzers, square-wave generators, germanium diodes, etc.—Electronics Dep't., General Electric Co., Syracuse, N. Y.

R-371 PHASE METER. 12-page bulletin describes and illustrates maker's "Type 320-A" phase meter for direct measurement of phase difference between two voltages. Principle of operation, specifications, dimensions, etc. are listed.—Technology Instrument Corp., Waltham, Mass.

R-372 RELAYS. 16-page Catalog No. describes and illustrates maker's line of relays for the electronic field; suited for electronic and industrial control, signal and traffic control, radio, aircraft, etc.—Phillips Control Corp., 612 N. Michigan Ave., Chicago 11, Ill.

R-373 INSTRUMENT TRANSFORMERS. 8-page bulletin describes and illustrates maker's "JKM-3" 5000-volt indoor model current transformer. Construction, ratings, accuracy, etc., are discussed.—Apparatus Dep't., General Electric Co., Schenectady 5, N. Y.